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NUCLEAR MEDICINE ENVIRONMENTAL DISCHARGE MEASUREMENT

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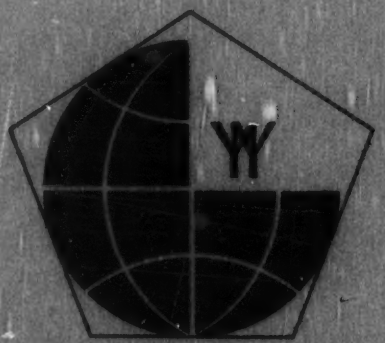
FINAL REPORT



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NUCLEAR MEDICINE ENVIRONMENTAL DISCHARGE MEASUREMENT

FINAL REPORT

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INTRODUCTION

STATEMENT OF PROBLEM

The discharge of most man-made radioactive materials to the environment is controlled by Federal, State or local regulatory agencies. Exceptions to this control include the radioactive wastes eliminated by individuals who have undergone diagnostic or therapeutic nuclear medicine procedures. Several previous efforts have been made to call attention to or quantify this unregulated release. (Scott, 1950; Ruchhoft and Feitelberg, 1951; Moss, 1972; 1973, Claridge and Kendrick, 1973; Strong, 1973; Sodd et al., 1974).

The purpose of this study is to estimate the amount of radioactivity released to the environment via the nuclear medicine pathway for a single sewage drainage basin and to measure the amounts discharged to the environment. The report is organized into a review of previous studies, scope of work, facility data, environmental measurements and estimates of population exposure.

REVIEW OF PREVIOUS STUDIES

The fate of radionuclides released to the environment by medical activities is not exclusively a recent concern. While it will probably never be known who first thought of this potential problem, published reports go back at least 25 years. With one exception, the early reports tended to dismiss the problem because the estimated concentrations were well below the "mpc's" provided by the various standard formulating bodies. Increasing use of radiopharmaceuticals has stimulated reevaluation of this source of man-made environmental radioactivity.

This section reviews and summarizes the important results of the previous studies in this area. Following the individual reviews of the previous work, a summary table is provided.

The 1950 Scott Study

This paper (Scott, 1950) makes estimates of radiation levels associated with assumed disposal of ^{131}I, ^{32}P and "rare earth fission product" wastes from patient excretion at the Medical Center of the University of California at San Francisco. A total of fifty therapy patients per day are assumed, of whom 20 are ^{131}I patients and as a result, one Curie per day of ^{131}I is estimated to be discharged to the sewer system. This discharge if diluted with the average sewage from a therapeutic ward is estimated to produce external radiation levels of ~50 mR/day in liter quantities. Skin exposures associtated with direct waste contact are estimated to be 40 times as great. Upon dilution with the entire sewage output of the Medical Center of the University of California at San Francisco, (5×10^5 1/day), liter quantities are estimated by Scott to produce external radiation levels of 3 mR/day. Exposure rates of less than 0.1 mR/day are estimated to be produced by sewage diluted with the entire flow (2.7×10^7/day) of the sewage plant serving the Medical Center. The potential concentration of the radioisotopes in the "sludge" or "filter cake" produced by secondary sewage treatment is recognized and levels estimated. One Curie of an isotope distributed in the daily production of filter cake is estimated to produce a concentration of 0.1 μCi/g. The use of filter cake for fertilizer is recognized and it is claimed that skin contact with the filter cake at the postulated concentration would produce

a skin dose of 2 rep/day.

The Scott paper is easy to criticize in the light of present knowledge. The basis for his estimates, 50 therapy patients per day, is very excessive; no corrections for radioactive decay are made and the assumption that all or most of the radioactivity would end up in the sludge is not supportable. Nevertheless, the paper did call attention to the potential for environmental contamination by nuclear medicine isotopes.

The 1951 Ruchhoft and Feitelberg (R & F) Study

This paper (Ruchhoft and Feitelberg 1951) was prepared in response to the Scott, (1950) paper reviewed above. This study replaced some of the speculations incorporated into the Scott (1950) paper with evidence. R & F obtained data on shipments of radioactive iodine and phosphorous to six large U.S. cities including San Francisco, made the conservative estimate that all activity received was released to the sewer systems and calculated expected average concentrations based upon reported water consumptions. They further pointed out experiments that had shown that only a few percent of the released activity would be expected in the sludge and that sludge detention times were greater than the half lives of the isotopes in question. They further pointed out that only about 1 mCi per day of ^{131}I was discharged from the Medical Center of the University of California at San Francisco whereas Scott used 1 Ci/day in his estimates. The authors concluded that the activity to be expected in the sludge would be "hardly sufficient to be distinguished from background".

The 1972 Moss Study

Although other studies on radioactive materials in sewage systems took place in the years between 1951 and 1972, these primarily treated fallout and natural sources of activity. An exception was the report of Effenberger and Hanchke (1967) which again called attention to the release of radioisotopes through patient excreta.

A major effort to quantify the release of radioactivity to a sewage treatment facility was made by Moss (1972, 1973), who studied the ALCOSAN sewage treatment basin and the medical institutions contributing radioactivity (Allegheny County, Pennsylvania) to it. Whereas Ruchhoft and Feitelberg had a relatively simple task in determining the amount of isotopes shipped to various cities in 1950 because of the single source of supply at that time, Moss had no such simple situation and had to survey the 21 institutions employing nuclear medicine isotopes in his area of study. He obtained, among other data, the annual number of each procedure performed for three years as well as the typical dose and isotope for each type of procedure. These data were used with excretion models and in/out patient ratios to estimate the amount of several isotopes released to the ALCOSAN Treatment Facility. These estimated releases were combined with flow rates to estimate concentrations to be expected in the sewage effluent. A few measurements were performed to verify the predicted values and order of magnitude agreement was observed.

The 1973 Claridge and Kendrick Study

This study (Claridge and Kendrick, 1973) was performed as an AEC contract. A previous AEC effort (Folsom and Mohanrao, 1961) had demonstrated that ^{131}I levels at the Los Angeles Hyperion Sewage Treatment Plant were 20 times lower than the mpc then in effect (quoted from Claridge and Kendrick, 1973) Claridge and Kendrick pointed out that a current review of the nuclear medicine isotope release situation was important for a variety of reasons. Among them:

1. MPC's have been reduced
2. Existing data on isotope releases are out of date.
3. The necessity to insure that no member of the public is unnecessarily exposed to radioactivity by uncontrolled releases
4. The rapid increse in nuclear medicine procedures in recent year.

This study gathered hospital data from 11 hospitals in four California cities. Nuclear medicine procedure data were reported by month for one year (1972) and by year for the three previous years. Data were reported by procedure, chemical form and isotope. A series of mathematical models were described but were not applied to the actual isotope data gathered from the hospitals. Thus no numerical estimates of releases or concentrations were given. The behavior of ^{99m}Tc and ^{131}I in one hospital sewage system was observed by flushing boluses down a toilet and observing the distribution in time of the concentration as it left the hospital. Twelve grab samples, 9 from the influent and 3 from the effluent of a sewage treatment plant were analyzed for ^{99m}Tc, ^{131}I and ^{203}Hg. The ^{203}Hg analysis failed, the ^{131}I values ranged to $\sim$20 pCi/liter and ^{99m}Tc to ~ 40 pCi/1. No activity measurements in sludge were reported.

The 1973 EPA Survey of Municipal Sludge Samples

The studies reviewed above heavily emphasized collection of data on nuclear medicine usages and estimation of releases. Actual environmental measurements, while performed in some cases were by no means extensive. In 1973, the EPA Office of Radiation Programs (Strong, 1973) analyzed sludge from 10 sewage treatment plants in 9 U.S. Cities. They identified ^{131}I, ^{203}Hg, ^{232}Th, ^{137}Cs, ^{214}Bi, ^{106}Ru, ^{103}Ru and ^{40}K in these samples. Iodine-131 activities ranged to ~ 670 pCi/kg of wet sludge.

The 1974 Sodd et al. Study

This study (Sodd et al., 1974) sought to determine the existence and levels of certain radioisotopes in the largest Hamilton County, Ohio sewage treatment facility which serves the Cincinnati area. This facility serves 11 hospitals and institutions involved with isotopic procedures. Composite samples were taken of the outfall from the sewage plant and grab samples were taken ten miles above and five miles below in the Ohio River. They showed that approximately 50-70 mCi of ^{99m}Tc and 6-24 mCi of ^{131}I were released daily to the sewage treatment plant. Hospital usage was estimated but details of the inventory were not reported.

Other Pertinent Work

Other studies which have a direct bearing on this work include those documenting the growth of nuclear medicine, analytical procedures, data reduction techniques and so forth. These will be discussed as necessary throughout the report.

Summary of Environmental ^{131}I Data

A summary of measurements and estimates of ^{131}data is given in table I. ^{131}I was chosen because it widely used in nuclear medicine and is quite hazardous. Other isotopes have been reported. It is interesting to note that with the exception of the first study in the table, (which was based upon unrealistic assumptions) the estimates and measurements tend to have reasonable order of magnitude agreement.

SCOPE OF THIS WORK

This study differs from the previous work in two significant areas. First, the hospital data were gathered daily rather than monthly or annually (or not at all). Second, environmental measurements have been made on a daily basis over a period of several months, thus allowing comparison of daily estimated releases with daily measured values.

TABLE I

PREVIOUSLY MEASURED AND ESTIMATED CONCENTRATIONS OF ^{131}I

IN SEWAGE AND SLUDGE IN U.S. CITIES

CITY AND DATE	MEASURED CONCENTRATIONS AND NUMBER OF SAMPLES ()			ESTIMATED CONCENTRATION			DAILY RELEASE	REF.
	Influent (pCi/l)	Effluent (pCi/l)	Sludge (pCi/kg)	Influent (pCi/l)	Effluent (pCi/l)	Sludge (pCi/kg)	TO ENVIRONMENT (mCi)	
San Francisco(1950)	-	-	-	3700*	-	100,000,000*	1,000	A
San Francisco(1951)	-	-	-	25	25	205	1	B
New York (1951)				40				B
St. Louis (1951)				60				B
Chicago (1951)				40				B
Los Angeles(1951)				60				B
New Orleans(1951)				40				B
Pittsburg(1971)***	-	0-41(5)	-	10.3	9.3	-	5.3	C
Berkley (1973)	7.7-23(9)	3.5(1)	-					D
Denver (1973)			57(1)					E
Baltimore(1973)			54(1)					E
Chicago (1973)			46(1)					E
Houston (1973)			467(1)					E
Boston(1973)			N.O.(1)					E
Philadelphia (1973)			N.O.(1)					E
New York (1973)			142 (1)					E
Los Angeles (1973)			674 (1)					E
San Francisco(1973)			328 (1)					E
Cincinnati		4-83(18)					3-24	F

* These values were based upon an unrealistically large estimate of 20 therapies per day

** REFERENCES: A - Scott, 1950
B - Ruchhoft and Feitelberg, 1951
C - Moss, 1972
D - Claridge and Kendrick, 1973
E - Strong, 1973
F - Sodd, et al., 1974

*** A 1966 report (Tresville, 1966) reported no measurable ^{131}I in Pittsburg sewage

HOSPITAL DATA COLLECTION

In a study of this nature, where one is concerning himself with the potential hazards to the population as a whole from excretion of radioisotopes by nuclear medicine patients, it is necessary to determine not only what radioisotopes, chemical forms and dosages are employed but also the excretion rates and pathways in order that the amount of each isotope actually entering the environment may be estimated.

Claridge and Kendrick (1973) made extensive studies of the hospital uses of radioactivity and attempted to account for all activity "received, stored, administered and released to the environment". It appears that the most interest would lie in the quantity administered to the patient or actually discharged into the sewer as a means of disposal. However, such discharge may be relatable by models to the quantity of activity received as well as hospital size, etc. An investigation in the Texas Medical Center has revealed that there is no intentional disposal into the sewer system; thus, the only source of measurable activity above background should then be the excrement of patients or introduction of waste radioactivity from other institutions such as universities and commercial users of radioactive material.

A determination of all possible contributions, other than from patients, to the sewer radioactivity of the Sims Bayou Sewer Plant was made and upon investigation, it was found the the only activity introduced into the sewer system is in the form of tritium and carbon 14 labeled compounds which are undetectable by the gamma counting equipment utilized in this study.

Licensee Survey - Methods

In cooperation with the Texas State Department of Health, Division of Occupational Health and Radiation Control, the Radioactive Materials Licensing Agency in Texas, a review of the procedures and records of all licensees who are located within the geographical area served by the Sims Bayou Sewage Treatment Plant, was attempted with particular emphasis on patient doses administered, in the case of medical institutions, and waste disposal in the case of both medical and industrial licensees. All such information gathered was made available through licensee cooperation and collected by personal visits to licensees by UTSPH researchers. It was desired that the data be taken in two distinct divisions. First general information about the hospitals and second, specific information about each patient. Complete coverage of every patient who has been through the nuclear medicine programs for a one year period beginning July 1, 1973, and ending July 1, 1974, was attempted. Appendix V-A contains a letter of the type sent to licensees and a copy of the general information form.

Hospital Survey

Within the study area, there are 9 hospitals which have active nuclear medicine programs. These institutions are:

1) Diagnostic Center Hospital
2) Center Pavilion Hospital
3) Ben Taub Hospital
4) Hermann Hospital
5) Methodist Hospital
6) M.D. Anderson Hospital

7) St. Luke's Hospital

8) Veterams Administration Hospital

9) Memorial Southeast Hospital

Reception of the project by hospitals varied from complete cooperation through lack of cooperation. One spokesman for a non-participating institution voiced his concern that patients rights to confidentiality might be violated and that patients treated in the institution he represented did not upon admission agree to allow any data concerning their treatment to be used in research. Further, he stated that, in general, he believed that cooperation with this project was not to the advantage of the hospital and that, in fact, it could be detrimental to the future practice of nuclear medicine.

In all instances, hospitals were assured of anonymity for both themselves and their patients. Whenever a representative of a hospital believed certain information, such as patient name, hospital number, etc., would compromise patient rights and confidentiality, the information was not included in our data. Some refused, however, for various reasons to even provide the number of patients for each test on a daily basis.

Of the nine hospitals in the study area, five have cooperated. Data from the five cooperating hospitals have been coded according to the code given in Appendix IV-B. The cards were then read and transferred to permanent storage on magnetic tape. There are approximately 25,000 individual patient records included in the one year study period for these institutions.

Data Processing Programs

Programs have been written for the Cyber 73 Computer at the University of Texas at Houston Research and Education Computer Center. These programs have sorted the data and produced tables as shown in Appendix IV-A.

Total monthly usage (administration to patients) by participating institutions of ^{99m}Tc and ^{131}I for the period July 1973 - July, 1974 is summarized in Figure 1.

The Claridge and Kendrick excretion model (Appendix V-C) was applied to the ^{131}I data and the results tabulated along with environmental measurements in Appendix IV-B. (See Chapter III for explanation of Environmental data). The values for F_μ (0.9 and 0.67) and λ_μ (3.55 and 2.90) given in the Claridge and Kendrick report were averaged in our computations, so that $F_\mu = 0.785$ and $\lambda_\mu = 3.23$.

The net result for ^{131}I in the NaI form is that 69.2% of the original dose is excreted by the end of the first day after administration, an additional 2.5% is excreted during the second day, and negligible amounts thereafter. The data were further modified in this computation by the exclusion of all single doses in excess of 30 mCi given in two institutions which were known to retain urines from such patients for decay. The daily ^{131}I excretion due to doses administered by the cooperating institution is plotted in Figure 2, along with total estimated environmental ^{131}I discharge. It is to be noted that during the study period, 630 mCi of ^{131}I was estimated to be excreted, while the measurements and calculations described in Chapter III indicate a total output of 155 mCi ^{131}I from the Sims Bayou Plant.

Correlation of Hospital and Environmental Data

The available hospital data corrected for excretion does not show significant degree of correlation with the environmental data. No improvement in correlation was observed when the environmental data was phase shifted forward by one, two, and three days to allow for possible delays due to

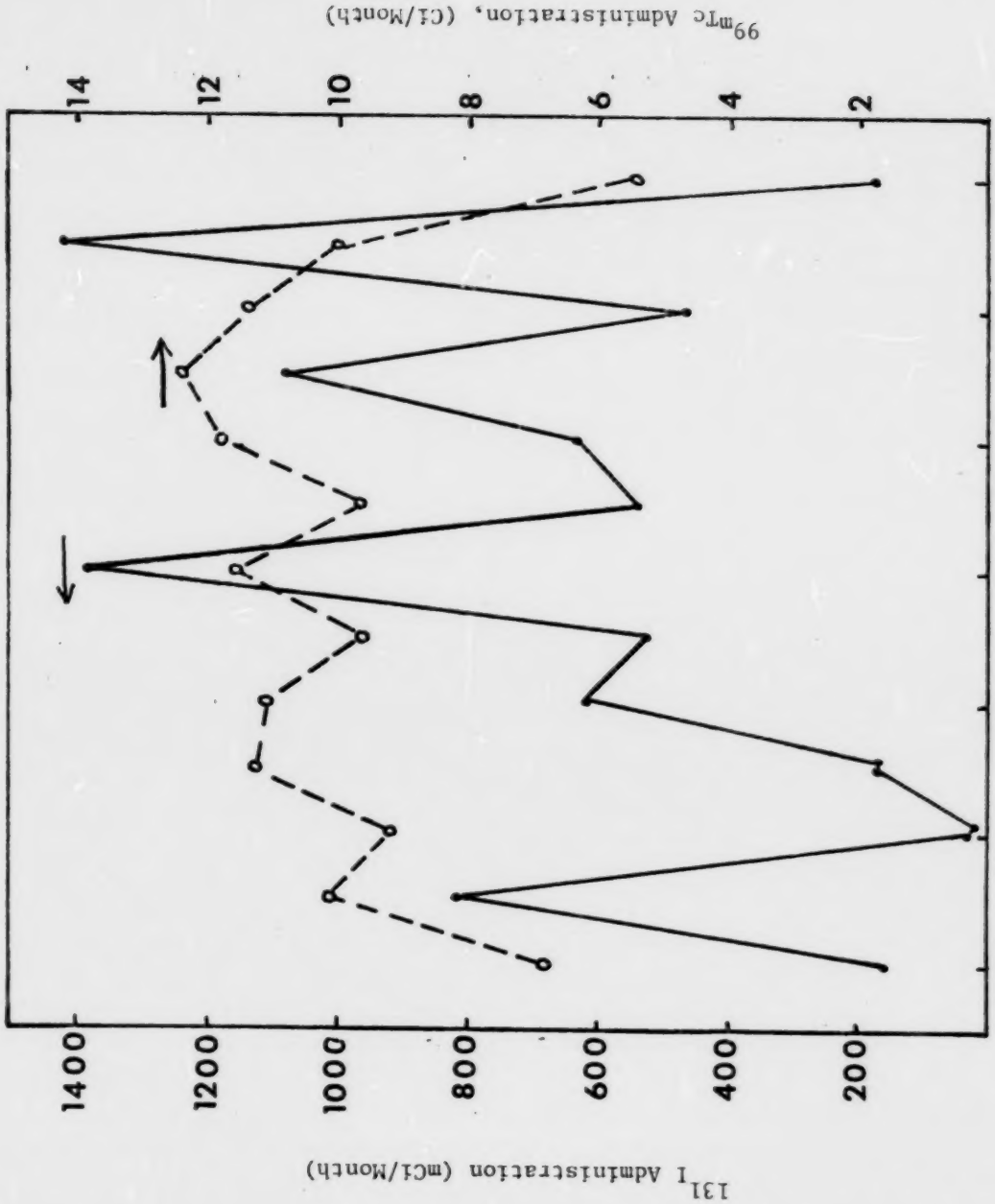


Figure 1. Monthly administration of ^{131}I and ^{99m}Tc to patients in the surveyed hospitals.

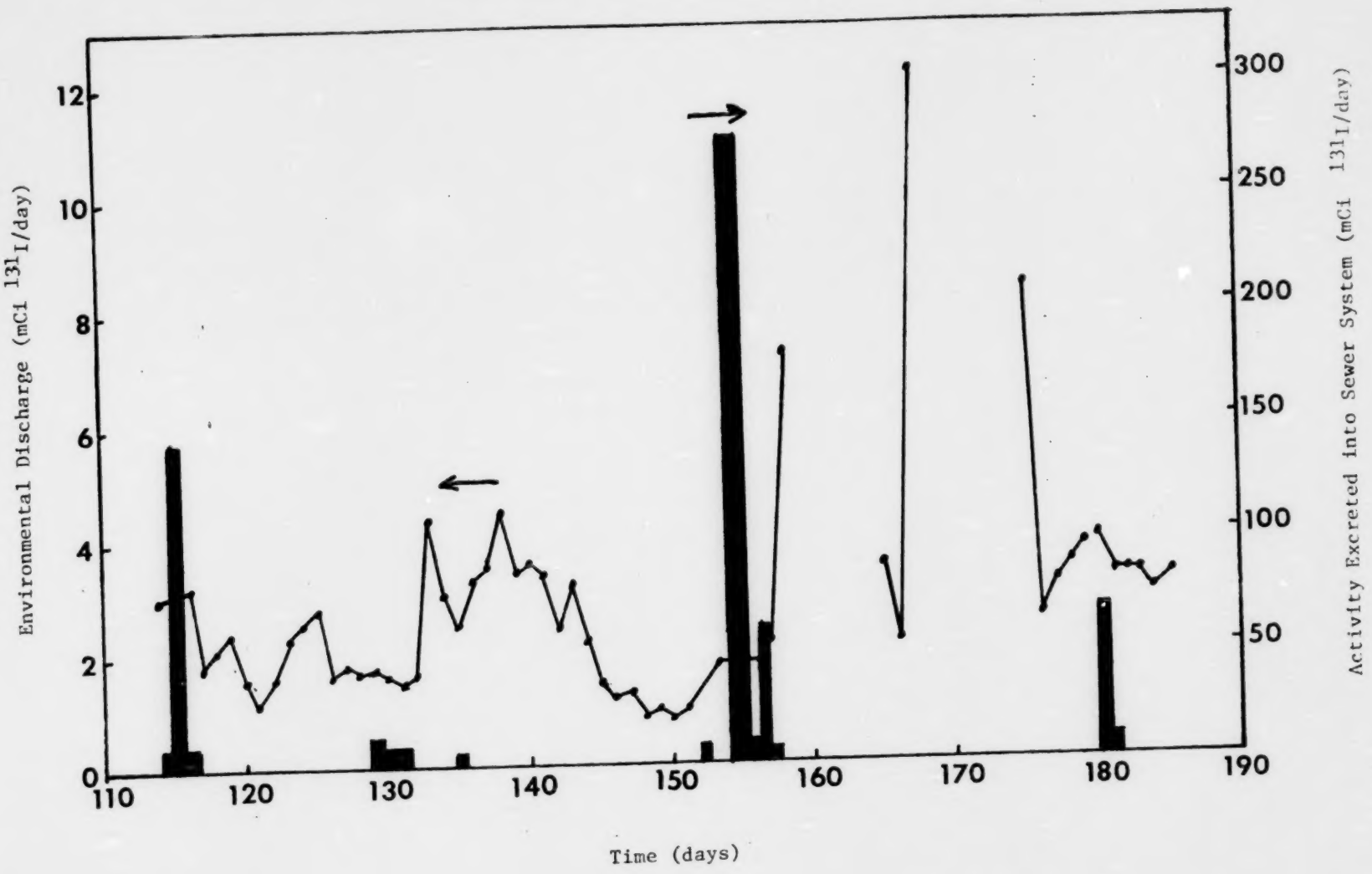


Figure 2. Comparison of the measured ^{131}I discharge to Sims Bayou and the estimated ^{131}I discharged by ^{131}I therapy patients.

sewage processing.

The lack of correlation is, unfortunately, to be expected from a priori considerations. Two of the participating institutions retain urines from ^{131}I therapies for decay, one institution is relatively small, does not perform ^{131}I therapies and infrequently does diagnostic work, and one large participating institution conducted an atypically small number of therapies during the environmental sampling period. The four non-participating institutions are all large hospitals with active nuclear medicine programs.

ENVIRONMENTAL MEASUREMENTS

The primary objective of the field observation program was to obtain a reliable measurement of the long-term average discharge of ^{131}I to the environment via the Sims Bayou Sewage Treatment Facility, which serves the Texas Medical Center and surrounding isotope-using hospitals and clinics. Other objectives included surveillance for other radio-isotopes in the sewage system and special environmental measurements as needed. The general procedure was thus to: (1) obtain and analyze grab samples from various stages of the sewage transport and treatment system (2) determine the time-scale of fluctuations in the radioisotope content of sewage plant output, (3) obtain a reliable estimate of the ratios of total ^{131}I output via stack gas, sludge, and supernatent at the Sims Bayou Plant, (4) maintain surveillance over the plant for an extended period of time and (5) make special measurements as needed.

EQUIPMENT

All field samples were analyzed by gamma spectroscopy at the low-level counting facility at the Geology Department at Rice University. The counting system consisted of twin 3" X 3" NaI (Tl) crystals connected additively to a 256 channel analyzer. An automatic sample changer facilitated the analyses of multiple samples. For a more complete description of the counting facility, see Adams, (1964). The output of the multi-channel analyzer was converted into decks of computer cards which could be readily stored and re-analyzed as needed.

CALIBRATION

Calibration standards of ^{131}I were obtained at approximately monthly intervals from the EPA Laboratory at Las Vegas, Nevada. The standards were thoroughly mixed with 130ml samples of the various media to be investigated (water, ion-exchange resin, and flame-dried sludge or ash) and packed into the sample tubes for counting. Calibration constants were thus obtained directly for each medium in sample

configuration. A similar calibration procedure was used for ^{99m}Tc. A sample of ^{99m}Tc assayed to ± 3% was obtained from the M.D. Anderson Hospital Radioisotope Laboratory for this purpose (See Appendix III for calibration data).

SAMPLING PROCEDURE

All samples, direct or concentrated, were packed into cylindrical sample tubes with an active length of 15cm. and volume of $130cm^3$. The net weight (or original unconcentrated volume) of the sample and the elapsed time between collection and counting were recorded on the data decks.

DATA ANALYSIS

It was originally intended that each sample be counted twice; once soon after sampling, and then again after 7 half-lives of ^{131}I. The second spectrum would then be used as a background for the first, and after background subtraction, the counts under the appropriate photopeak would be summed and multiplied by the calibration constant for that medium. However, it soon became evident that ^{131}I so completely dominated the sample spectra that the original plan would be (1) unnecessary for ^{131}I, and (2) impractical for shorter-lived isotopes with similar or lesser photopeak energies because of the uncertainties involved in accounting for the large ^{131}I Compton shelf (See figures 3 and 4). The method of Covell (1959) was found to be well suited to our needs. The photopeak area is computed by summing the channels in the range $I-\Delta I$ to $I + \Delta I$ and subtracting the trapezoidal base area. (A computer program capable of handling multiple isotopes with this method was developed and used to reanalyze previous standard and sample runs, as well as subsequent data.)

RESULTS OF SAMPLING PROGRAM

Preliminary Grab Samples

Samples of effluent from the Texas Medical Center, influent and effluent at the Sims Bayou Treatment Plant, and sludge at various stages of treatment were analyzed with the low-level gamma spectrometer. (See Appendix I for a description of the sewer system and processing plant).

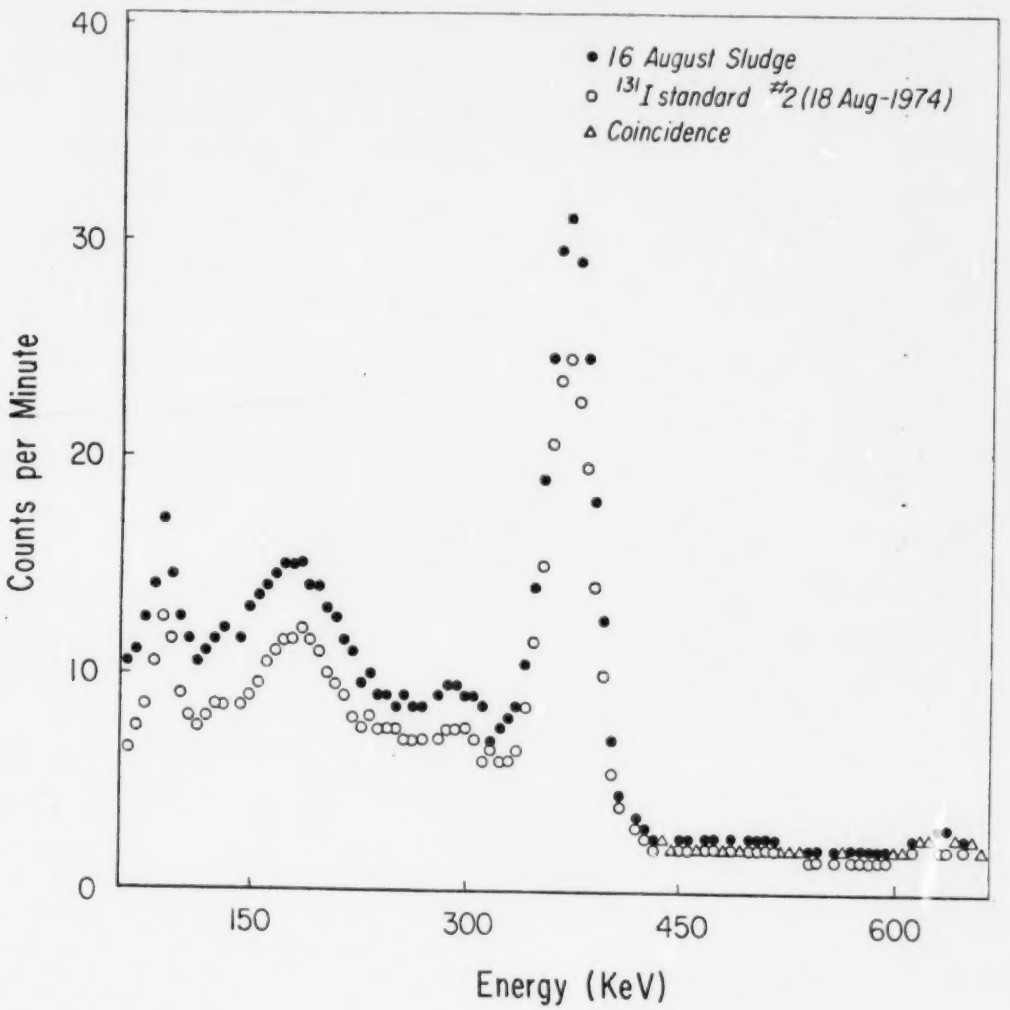


Figure 3. Comparison of gamma spectra from an ^{131}I standard and a typical vacuum dried sludge sample.

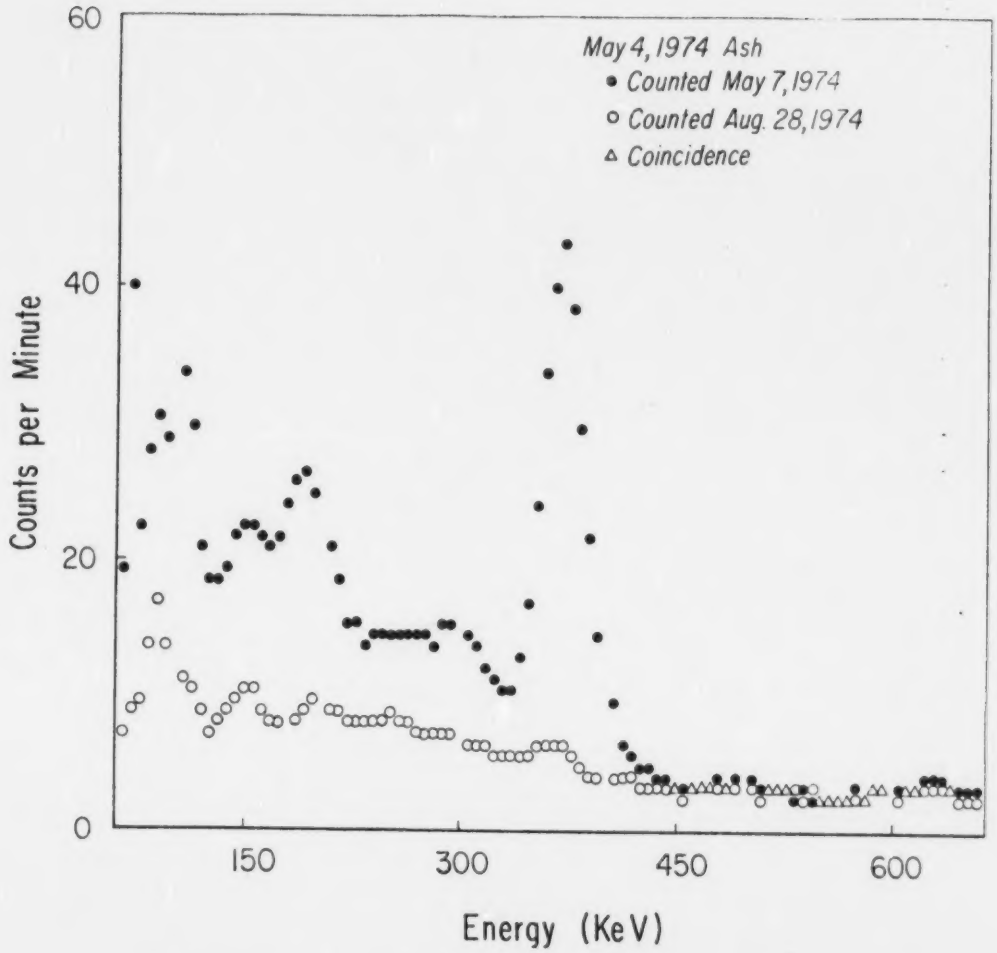


Figure 4. Comparison of gamma spectra from a typical flame dried ash sample and the same sample counted 3 1/2 months later.

The highest activity was found in the sample from the final stage of sludge processing, i.e., the flame-dried ash, which is used commercially as a soil conditioner. Activity was also noted in the "vacuum-dried" sludge, which is the immediate precurser to the ash, and to a lesser extent in the effluent from the Medical Center. The other samples did not show statistically significant activity following a 400 minute count. A fresh sample of flame-dried ash from the Northside Treatment Plant also showed no significant excess activity in the region of the ^{131}I peak.

Short-Term Temporal Variation

It was anticipated that because the nature of the treatment facility involves considerable recycling, that significant variation in the concentration of ^{131}I in the sludge would not occur from hour to hour in the course of a given day. To confirm this assumption an hourly sampling program over a 24 hour period was undertaken. Samples of both the flame-dried ash and the vacuum-dried sludge were taken; the results are given in figure 5. The lack of major hourly variations confirmed the supposition that daily samples would be adequate to characterize the emissions from the plant.

Collaboration with Eastern Environmental Radiation Facility (EERF)

In addition to the prominent ^{131}I peak in the spectrum of the preliminary ash samples, several other peaks were observed at energies suggestive of the isotopes ^{99m}Tc and ^{99}Mo, among others. It was decided that an analysis on a Ge(Li) system would be highly desirable in order to more definitely resolve the lines. On April 4, 1974 a fresh sample of the ash was flown to EERF at Montgomery for analysis. The suspected ^{99}Mo peak was in fact that of the ^{95}Zr - ^{95}Nb complex. An activity of 37.45 pCi/g of ^{131}I was measured. A portion of the same sample was retained for analysis on the spectrometer employed in this study. Unfortunately, difficulties with the mechanism prevented analysis until 16 days after sampling,

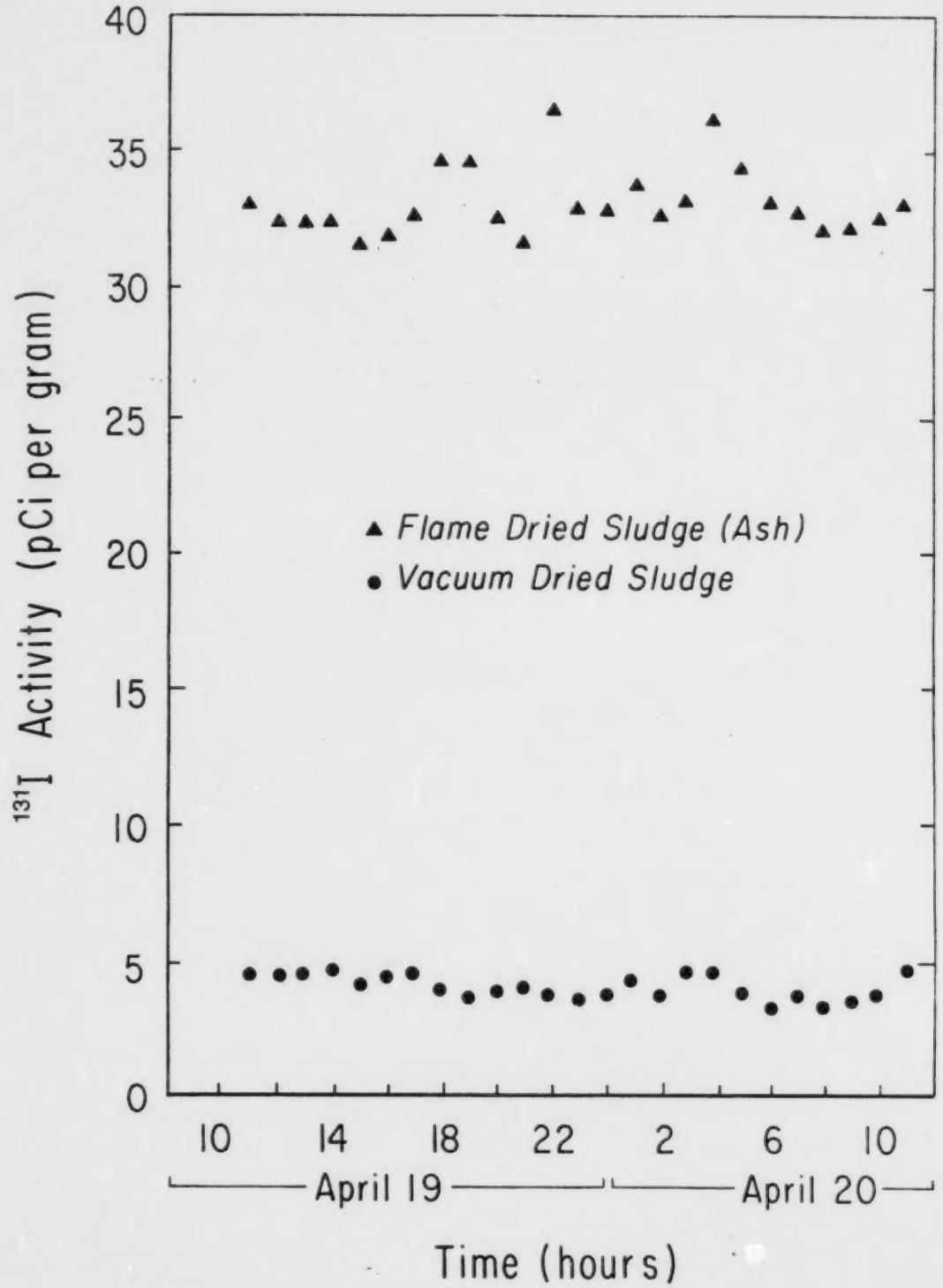


Figure 5. ^{131}I concentration in 25 consecutive hourly sludge and ash samples.

thus necessitating a large decay correction. The resulting measurement of 37.8 pCi/g was therefore considered to be in agreement with the EERF measurement.

Plant Effluent

Unconcentrated samples of the plant effluent displayed no detectable amounts of ^{131}I. However, as the volume of the effluent is quite large,(~50 million gallons per day), concentration techniques were used to aid in the determination of the total activity discharged into the environment. An ion exchange system similar to that described by Hasuike and Windham (1973) was used to sample effluent volumes as large as 120 liters. The principle differences in method were that two anion beds and one cation bed were used rather than vice versa, and that a peristaltic pump set at 300 ml/minute was used instead of a gravity feed and reservoir system. The resin beds were counted directly; no elution technique was used. In the course of the first few measurements, it was found that negligible activity was retained by the cation bed and the second anion bed. To further ascertain whether a significant fraction of the ^{131}I might not have been collected by the ion exchange resin, a 6 liter effluent sample was collected for evaporation concurrently with one of the ion exchange samples. Small amounts of the effluent were withdrawn from the outfall at regular intervals during the collection of the ion exchange sample. The six liter effluent sample was evaporated to a volume of 250ml over low heat and placed in two sample tubes. The activity of the evaporated sample was found to be 111 pCi/l, in excellent agreement with the activity of 110 pCi/l in the ion exchange sample.

Additional effluent samples were then taken continuously over a 24 hour period with the flow rate set at or near 30 ml/m. In all, 13 such samples of the plant effluent were taken at various times during the investigation, 6 at the higher flow rate with sampling times ranging from 3 to 6 hours, and 7 at 30ml/m for 24 hours sampling periods. In all but two of these cases, samples of the flame-dried

ash were taken concurrently. The ^{131}I activities per gram of ash and liter of effluent were then obtained and multiplied by the total outputs of ash and effluent respectively for that day. The resulting partition of ^{131}I is displayed graphically in figure 6. For the eleven days represented by these samples, the average ratio of ^{131}I discharged via the effluent to that discharged via the ash was 3.3 : 1.

Ash and Sludge

The flame-dried ash and the vacuum-dried sludge were selected as the products most suitable for regular daily monitoring. On April 23, 1974, regular sampling of these materials was begun. Except for occasional intervals when the sludge treatment plant and/or the spectrometry system were down for repairs, monitoring was continued through the middle of August. In figure 7, the activity of the ash is plotted against the activity of the vacuum-dried sludge that same day. A high degree of linearity and a large value of the correlation coefficient (.987) was observed. A slope of 6.27 $\pm$ .16 pCi/g ash per pCi/g sludge was determined.

On eight different days, samples of vacuum-dried sludge were brought to the laboratory and heated to dryness in order to simulate the flame-drying process. Percentages of solids in the sludge ranged from 11.8 to 17.5, with an average of 14.4 $\pm$ 1.7% solids by weight in the sludge. The dry ash is 93.4% solids by weight. Thus, 6.5 $\pm$ 1.6 grams of wet sludge are required to produce one gram of dry ash. The ratio of 6.27 pCi/g ash per pCi/g sludge therefore indicates that no significant quantities of ^{131}I are emitted via the stack gases in the flame drying process. No stack gas ^{131}I sampling was carried out, however.

Summary of Sims Bayou Plant Measurements

1. The highest concentrations of ^{131}I occur in the sludge cake and the flame dried ash produced from it.

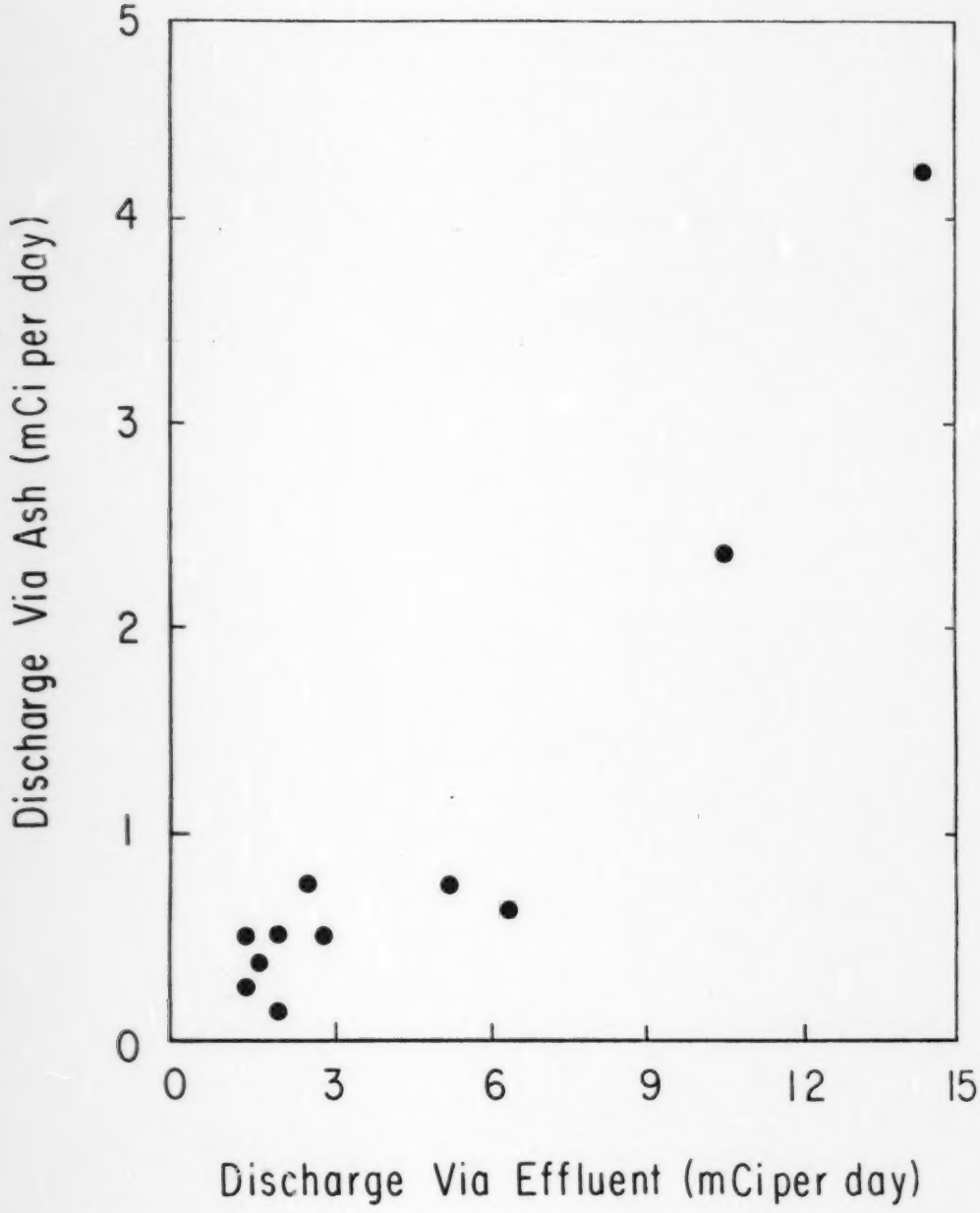


Figure 6. Relationship between ^{131}I activity discharged by the flame dried sludge (ash pathway) and the liquid effluent pathway.

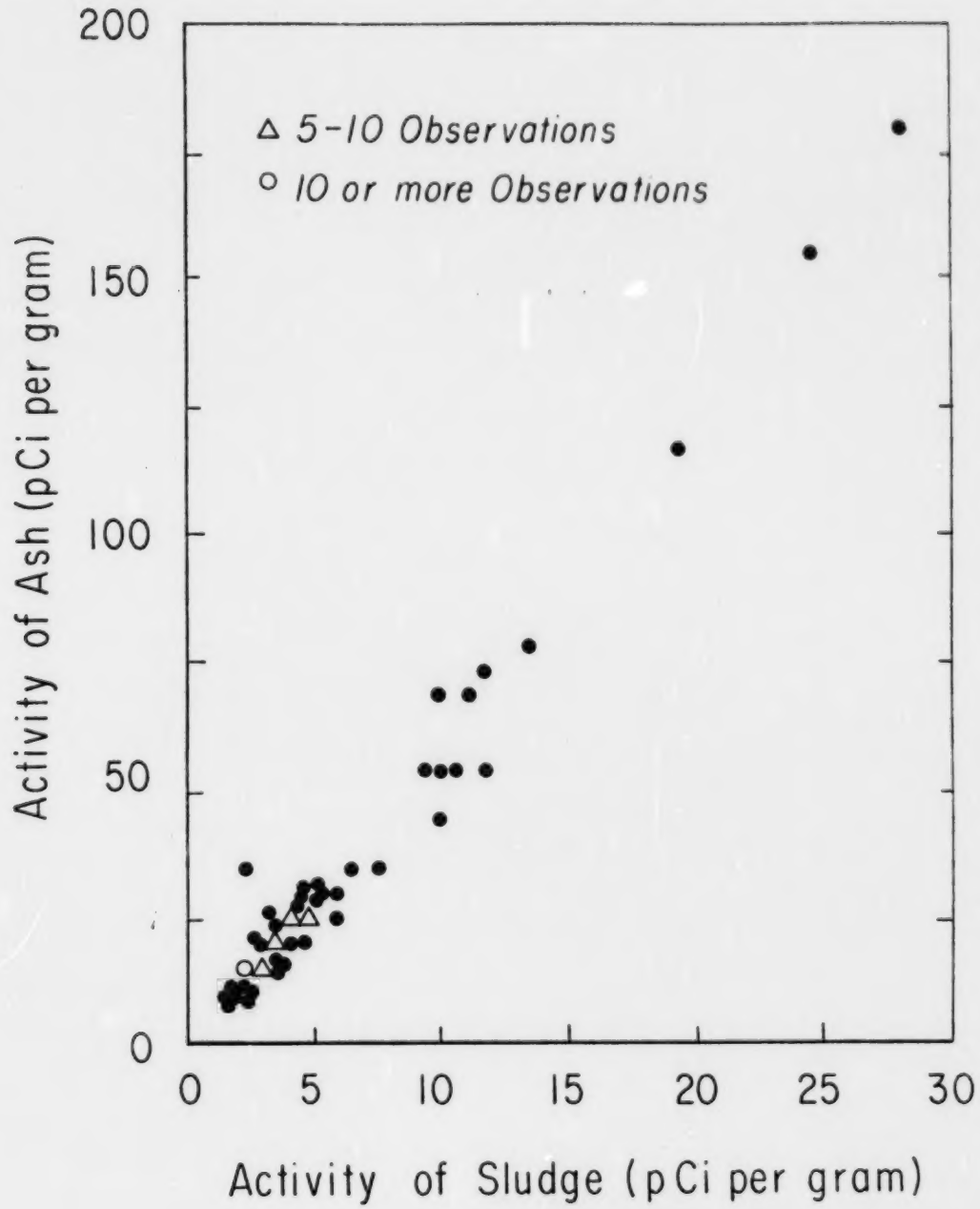


Figure 7.-- Relationship between the ^{131}I activity concentration in vacuum dried sludge and flame dried sludge (ash).

2. Significant variations occur on a time scale of days, but not hours.

3. Based upon a mass balance approach, virtually no ^{131}I activity is lost to the atmosphere during the flame-drying process.

4. There exists a reasonably linear relationship between the total ^{131}I emmission via the effluent and via the ash when the plant is operating normally. Approximately 77% of the ^{131}I emission is contained in the effluent, with the remaining 23% in the ash. A good estimate of the total plant emission of ^{131}I during the observation time can be obtained by multiplying the daily concentration of ^{131}I in the ash by that day's quantity of ash and by the factor 4.3. This estimated daily output is plotted in Figure 8. A frequency distribution of total daily output is presented in Figure 9. The daily average discharge of 4.37 mC_i (n=88 days) implies an annual discharge of 1.60 Ci/yr.

Marine Life

To investigate the possibility that ^{131}I was being concentrated by marine organisms, samples of oysters growing at Morgans Point off the Houston Ship Channel were taken. Morgan's Point (map, figure 10) is the point closest to the Sims Bayou effluent at which oysters grow. Due to contamination from the municipalities and industries along the ship channel, these oysters are not considered fit for human consumption.

One quart of oysters (exclusive of shells) was evaporated at 105° C and the residue placed inside our standard 130 ml counting tube. A control set of oysters from Redfish Reef in Galveston Bay was processed in a similar manner. Both tubes were counted and the spectra compared (figure 11). No evidence of enhanced ^{131}I activity in the oysters taken from Morgan's Point was observed. In view of the fact that the flushing time of the Houston Ship Channel from the Turning Basin to Morgan's Point is 38 days (cf. Appendix I) or nearly five half-lives of ^{131}I, the lack of activity was not surprising.

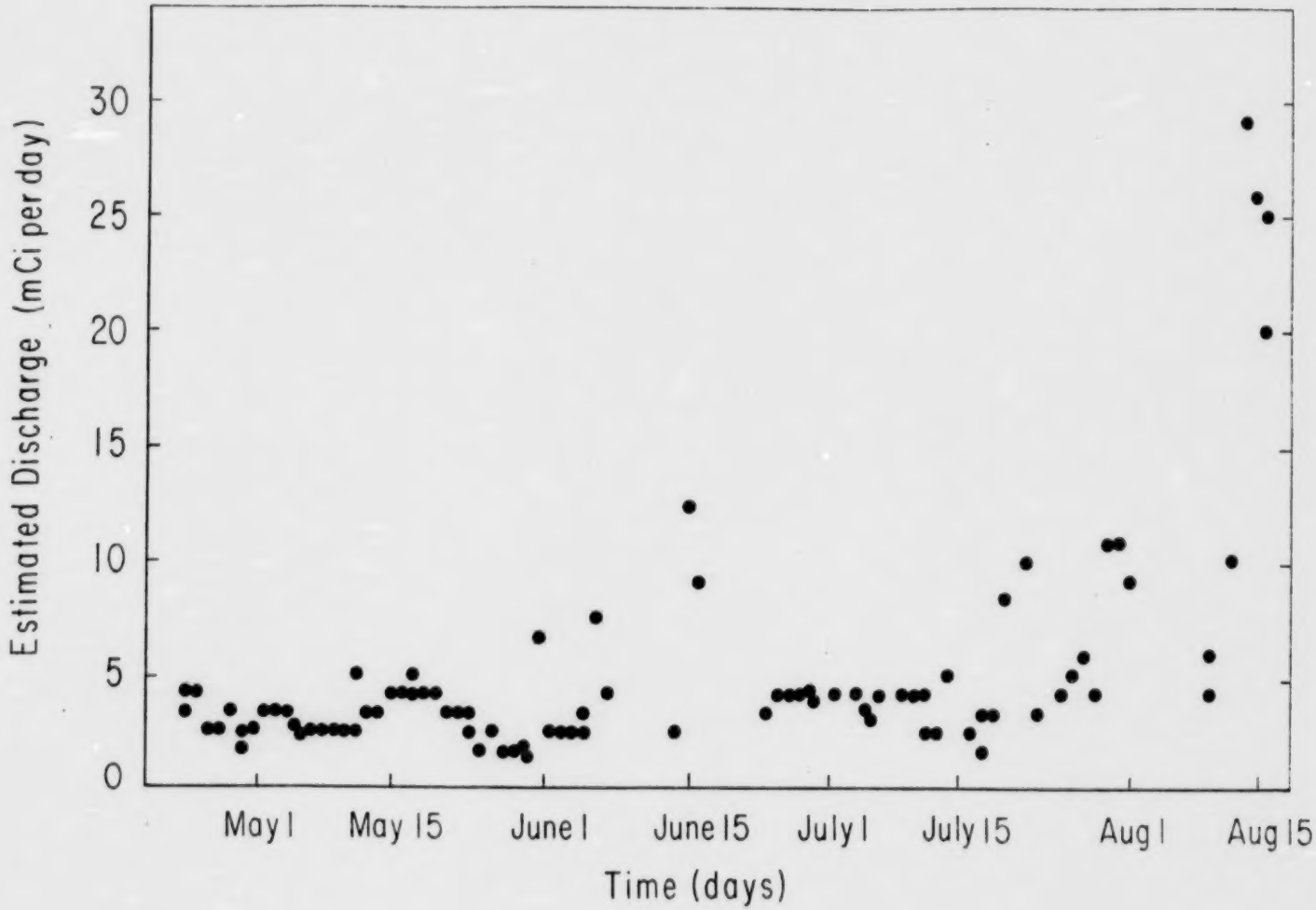


Figure 8. Daily discharge of ^{131}I to the environment for the study period, as extrapolated from sludge measurements.

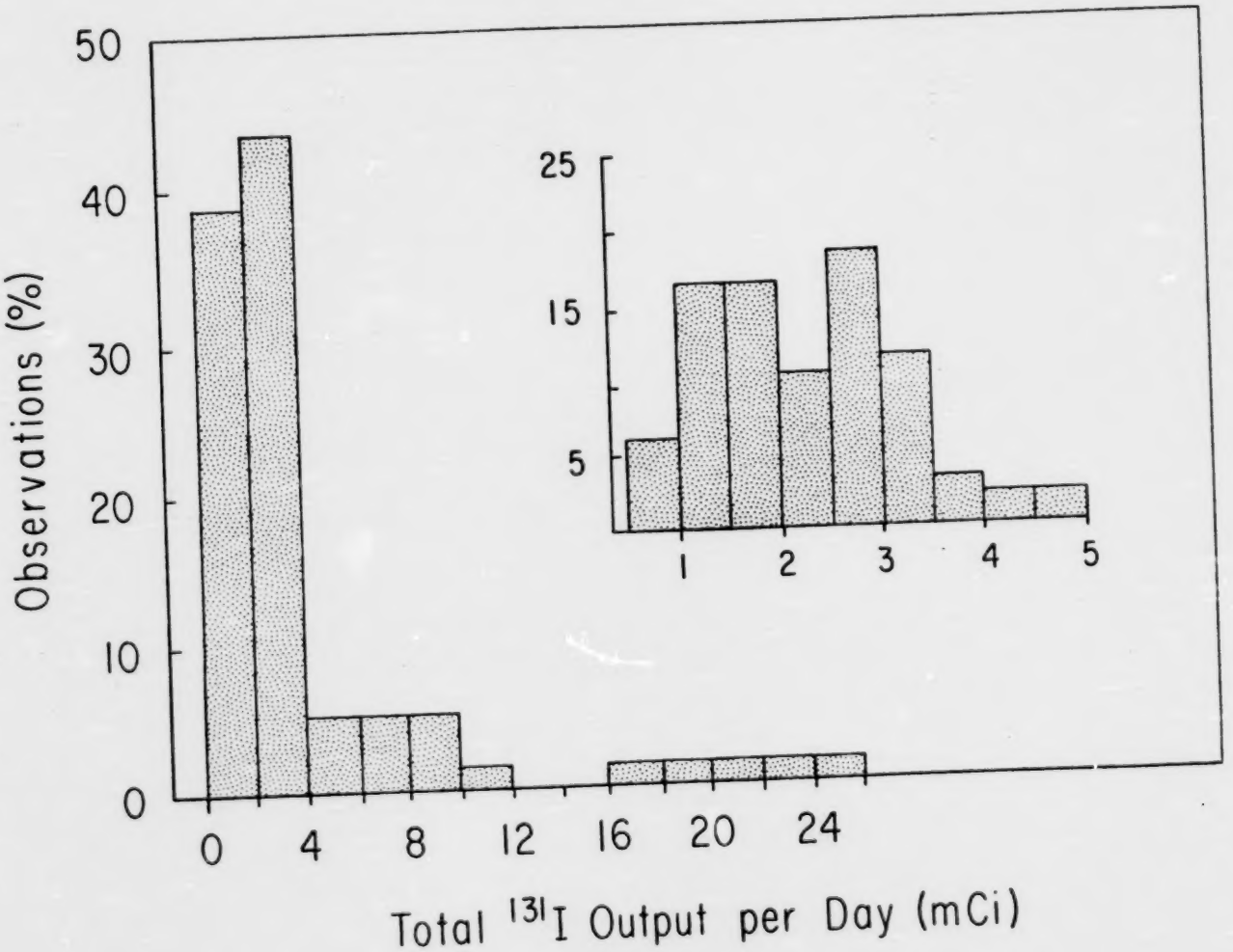
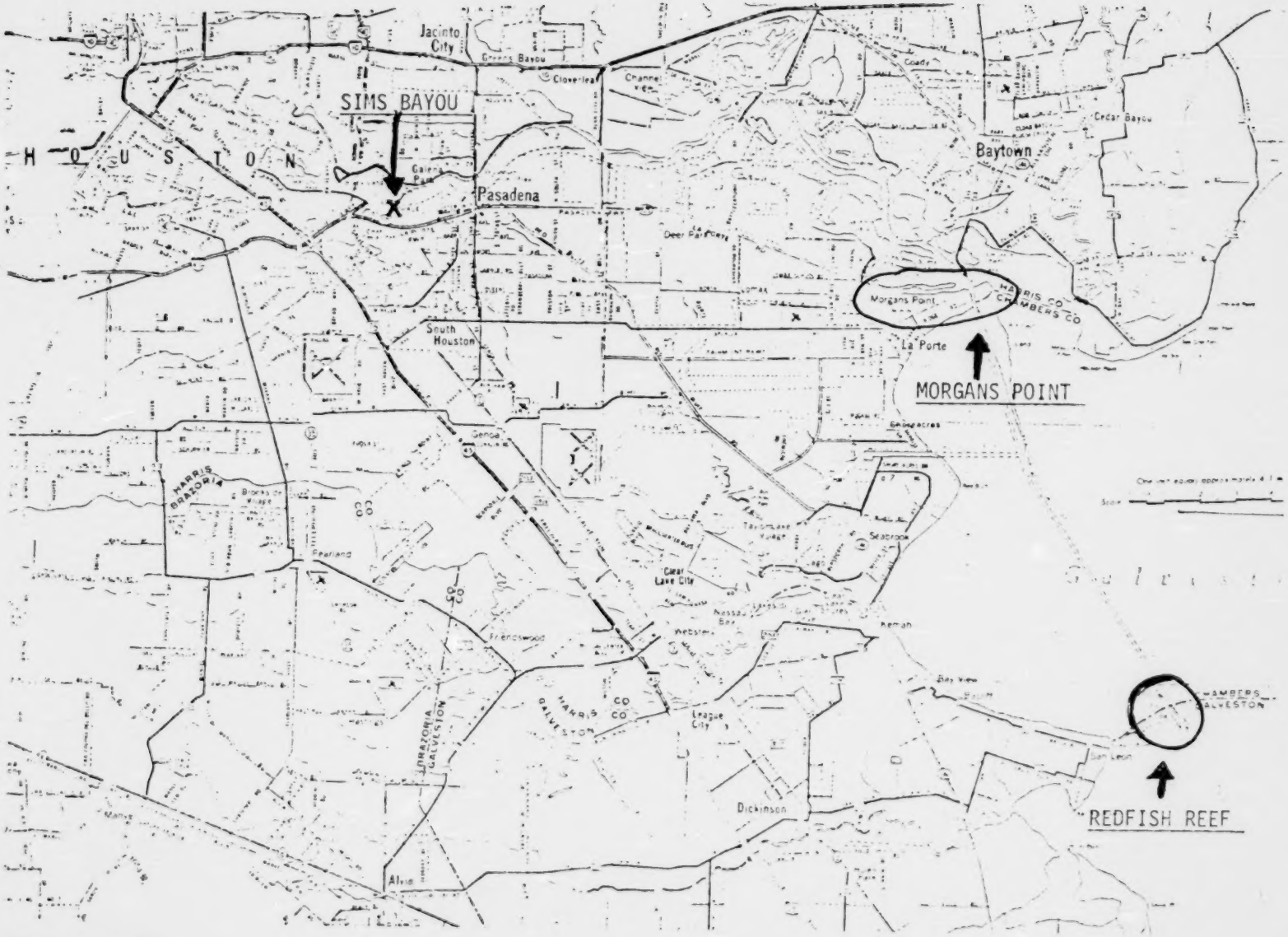
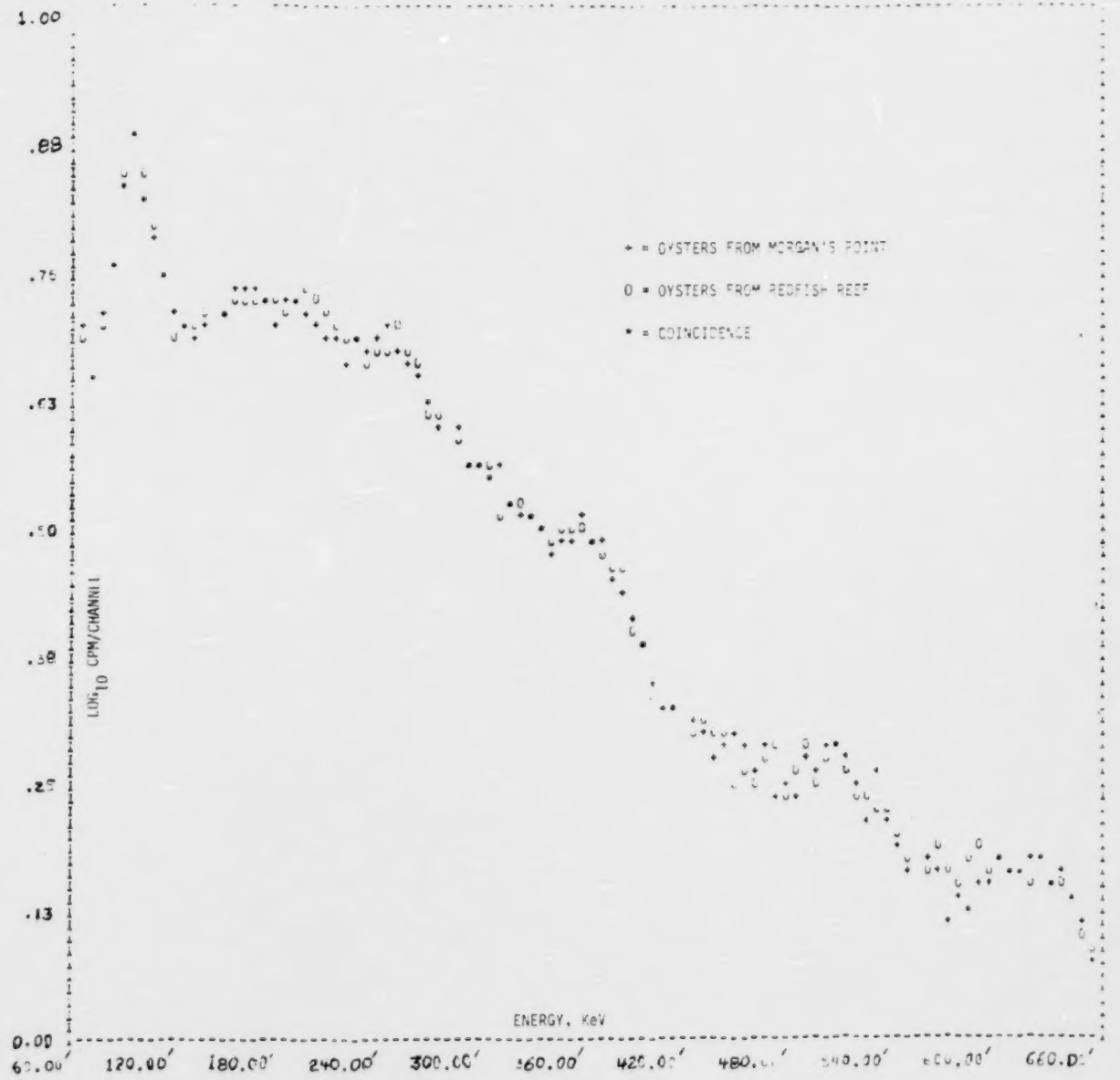


Figure 9. Frequency distribution of daily ^{131}I discharge to the environment.



Reproduced from best available copy.

Figure 10. Map of Houston Ship Channel and nearby areas.



GAMMA SPECTRA OF OYSTERS TAKEN FROM MORGAN'S POINT AND REDFISH REEF

Figure 11. Gamma spectra of oysters taken from Morgan's Point and Redfish Reef.

^{99m}Tc

Measurement of ^{99m}Tc was a secondary objective of this study. Because of spectrometer scheduling and other practical considerations, only about a quarter of the daily samples were analyzed within 5 half lives of ^{99m}Tc (i.e., ~ 30 hours). Of the 19 samples of ash counted within this time, 17 showed a clearly visible peak at 0.140 MeV. The average activity of the ash for the 19 days was 12.1 pCi/g, and for the sludge 2.41 pCi/g. The activity per gram of ash is, on the average, 5 times that of the sludge.

Five effluent concentrates were counted within 30 hours of collection. For those involving sampling times of 24 hours or more, it was assumed that the concentrations of ^{99m}Tc was constant throughout the sampling time, and the activity present in the resin bed at pick up time was representative of the equilibrium situation. The high flow-rate samples involved collection times of four hours or less, so the mid-point of the collection time was taken to be t_o. There were no intermediate collection times.

As with ^{131}I, the activity per liter was multiplied by the effluent volume for that day. The resulting effluent discharges ranged from 2.6 mCi/d to 11.8 mCi/d, with an average value of 6.9 mCi/day. An attempt to correlate effluent activity with ash activity was inconclusive, primarily because of discontinuous operation of the flame-drying apparatus during this phase of the study. While an uncertainty of 12 hours in the age of an ash sample was unimportant in the case of ^{131}I ($t_{1/2}$ = 193 hours) it is a serious limiting factor in the case of ^{99m}Tc ($t_{1/2}$ = 6.05 hr)

Assuming that the average effluent discharge and ash discharge are representative, the total annual discharge of ^{99m}Tc is:

$$365\ d\ [6.9\ mCi/d\ (effluent) + 12.1\ pCi/g\ (ash) \times 48.2\ Tons/d \times 10^{-3}\ mCi\text{-}g/pCi\text{-}ton]$$

$$= 2730\ mCi/yr.$$

POPULATION DOSE

Introduction

Based upon usage, finite quantities of the several radionuclides used in nuclear medicine can be predicted to enter Sims Bayou from the Sims Bayou Treatment Plant. This discharge is verified for ^{131}I and ^{99m}Tc which have been observed in the discharge as well as in the sludge produced by the treatment plant. It is our conclusion that for this particular case, individual and population doses due to nuclear medicine isotopes discharged to sewer systems are negligable and not worthy of detailed calculation. Justification for this conclusion is given below. A detailed calculation of the population dose due to atmospheric release of ^{133}Xe was performed. The results indicate individual doses ranging to 2.5μrem/yr whole body and an estimated population dose of .083 man-rem/yr whole body. This calculation together with the assumptions and limitations associated with it are also described below.

Discussion of exposure pathways

The conclusion that detailed calculations of population dose due to nuclear medicine isotopes released to the sewage system are unwarranted is dependent in part on the pathways by which released radionuclides may be returned to man in this particular situation. These potential pathways include the following:

1. use of diluted effluent for drinking water supplies.
2. use of flame-dried sludge as a fertilizer and soil conditioner with subsequent return of radionuclides to man via the food chain.
3. release of isotopes to the atmosphere during the flame drying process with the subsequent pathways that airborne releases imply, i.e., direct inhalation, cloud dose, deposition on agricultural land, crops, watersheds, etc.

4. uptake of isotopes by aquatic organisms ultimately resulting in return to man via the food chain.

5. Occupational exposure by direct radiation or by inhalation of isotopes.

Nuclear medicine isotopes have for the most part short half lives. Thus the time required for a radioisotope to return to man after discharge into the sewage system is an important variable.

The contribution to population dose by pathway number one is non-existent because no human drinking water supplies are taken downstream of the effluent of the Sims Bayou treatment plant. Sims Bayou flows into the Houston Ship Channel which flows into Galveston Bay which in turn empties into the Gulf of Mexico. Furthermore, no drinking water supplies are likely to be taken from these areas because they are tidal and therefore saline. In addition, the less saline portions of Sims Bayou and the ship channel are heavily polluted.

It should be stressed, however, that the situation in Houston is by no means universal. On the inland river basins, there is multiple use of water and it can be anticipated that drinking water supplies will contain nuclear medicine isotopes. The data developed in this and previous reports could be used to estimate population doses along inland rivers. In Houston, however, this pathway does not lead to ingestion of radioactivity by humans.

Pathway number 2 is insignificant because of the time required for the shipment processing and use of the flame dried sludge as a fertilizer - soil conditioner added to the time required to plant, grow, harvest, and market a crop. A minimum period of several months would seem to be required for this series of events, during which time the isotopes would decay by many half lives.

Pathway number three does not appear to be important because the activity

balance between the wet sludge and the dry sludge performed as part of the field measurement program indicated that virtually no ^{131}I activity was lost in the drying process. Since iodine is the potentially most volatile of the nuclear medicine isotopes, it would appear that stack releases are minimal. Nevertheless, no stack gas measurements were performed and since the activity balance is not error-free it is possible that some iodine is vented. It is strongly suggested that any future work incorporate stack gas analysis.

The significance of pathway number four, like that of pathway number two, is minimized by the long time period required to return the isotope to man. For example, it has been determined (see Appendix I) that the flushing time from the Houston turning basin (located about 4 miles upstream from the point where Sims Bayou enters the ship channel) to Morgan's Point (the point nearest the ship channel where oysters grow) is 38 days. Furthermore, measurements of oysters gathered at Morgan's point showed no detectable ^{131}I.

The occupational exposure (pathway five) has been examined to the extent of an external radiation survey and a one day air sample taken in the dry sludge storage warehouse. The external survey (G-M Survey meter) revealed no levels about background. A one day air sample revealed $\sim$ .03 pCi/m^3 of ^{131}I and the presence of several fallout isotopes and isotopes induced naturally by cosmic rays. The .03 pCi/m^3 of ^{131}I may be compared to the AEC (NRC) occupational exposure standard of 9000 pCi/m^3.

Atmospheric release of ^{133}Xe

Population and individual doses due to the atmospheric release of ^{133}Xe used in nuclear medicine were estimated using the AIREM computer code (Martin, et al., 1974). The code solves a sector-averaged gaussian diffusion equation

and then converts the predicted concentrations to doses. It was originally developed for estimating exposure due to atmospheric releases from nuclear facilities. The program input data requirements include amount of radionuclide released, stack height, population data by sector and radius, and meteorological data. The sources of these data and their limitations are discussed below.

Population Data

The source of radioactivity was taken as the geographic center of the Texas Medical Center. One hundred and seventy six sectors were formed; the boundaries of the sectors consisted of 16 equally spaced radii and 11 concentric rings. The spacing of the concentric rings was asymetric with closer spacing near the assumed release point. The area covered had a radius of 20 km and included most of the city of Houston as well as some non-city area in Harris county. After the sectors were formed, the population in each sector was determined by summing the block populations in each sector. The total population in the studied area was 1.33 million.

There are several limitations to these population data. First, the census data are five years old and the growth rate of Houston has been among the highest of American cities. Second, the data reflect place of residence rather than occupation. Since the nuclear medicine diagnostic procedures are performed predominantly during "business hours" on weekdays, the population distribution is certainly shifted and probably shifted toward the Medical Center. Nevertheless, the population data were judged to be adequate for a first approximation of the doses.

Meteorological data

The airem code requires meteorological data of the type normally gathered by Nuclear power plant operators and prospective operators. The cost of gathering these data at the site of the Houston Medical Center would have exceeded by

several times, the entire cost of this contract. Accordingly, the data gathered at the nearest nuclear power plant site were obtained from the Environmental Report (Houston Lighting and Power Co., 1973). This power plant site is approximately 45 miles west of Houston and the meteorology can be expected to differ slightly. These differences can be expected because of the urban nature of Houston vs. the rural nature of the site plus the geographic displacement; the site is somewhat further from the Gulf of Mexico and can be expected to be less influenced by the Gulf. Nevertheless, these data are the best available.

Stack height

The "stack height" was chosen quite arbitrarily as 20 meters since the nuclear medicine laboratories are usually located on elevated floors.

Annual release of ^{133}Xe

An estimate of the total release of ^{133}Xe should include all ^{133}Xe used in patients plus any ^{133}Xe released either routinely or by accident. Since no practical way was devised to estimate the ^{133}Xe lost routinely or by accident, only the estimated ^{133}Xe used in patients was employed in this estimate. Even this number was difficult to get because of the non-participation of three of the hospitals. Fortunately, investigators at one of the non-participating hospitals published a paper on indoor levels of ^{133}Xe in nuclear medicine laboratories (LeBlanc and Johnson, 1975) and revealed their workload range (20-25 studies/week) and dose range (15-24 mCi/study). By taking the midpoint of both the work load and the dose ranges, it is possible to estimate a usage of 23 Ci/yr. This estimated usage has been used to estimate usage in the other non-participating hospitals (by bed number ratios) and then added to the usage determined for the participating hospitals. In all an estimated 60 Ci are used per year in the study area.

Results of the calculation

The total estimated whole body population dose due to the release of ^{133}Xe used in nuclear medicine in Houston is 0.083 man-rem. The analogous skin population dose is estimated to be 0.2 man-rem. The maximum sector-averaged individual whole body dose is 2.9 μrem/yr and the skin dose is 5.5 μrem/yr. The detailed output is given in appendix V.

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APPENDIX I

WASTE DISPOSAL SYSTEM

INVESTIGATION OF WASTE DISPOSAL SYSTEM

Sample Station Locations

Engineering scale blueprints were obtained from the sewage treatment division, City Hall, Houston for identification and location of the sewage mains in the vicinities of each of the hospitals to be investigated. It was soon discovered that despite the continual effort on the part of engineers and draftsmen in that division, information is lacking on the exact location of some mains and their associated manholes. Personnel in the engineering or maintenance divisions of each hospital were contacted to aid in locating the discharge main from each hospital.

The following list contains the hospitals which are considered for this investigation and whether or not they are isotope users.

1. Diagnostic Center Hospital (yes)
2. Center Pavilion Hospital (yes)
3. Texas Medical Center (includes):
    a. Ben Taub Hospital (yes)
    b. Hermann Hospital (yes)
    c. Methodist Hospital (yes)
    d. M.D. Anderson Hospital (yes)
    e. St. Luke's Hospital (yes)
    f. Texas Children's Hospital (no)
    g. Shriner's Hospital (no)
    h. Texas Institute for Rehabilitation and Research (no)
    i. Texas Research Institute of Mental Sciences (no)
4. Veterans Administration Hospital (yes)
5. Mercy Hospital (no)

6. Gulfway General Hospital (no)

7. Memorial Southeast Hospital (yes)

Of the users listed above, all in the 1,2, and 3 categories combine their wastewaters in a centrally located 60" main. A station has been located in that main which will yield representative samples. Hospital #7 is located south and east of the Medical Center, roughly 3/4 of the way to the Sims Bayou Plant.

After leaving the Medical Center in the 60" main, the wastewater enters an uplift pumping station located East of MacGregor Drive and is then transported by gravity through a 60" main in a direct line to the Sims Bayou STP. The exact time of travel has been estimated to be between two and four hours. Figure I-1 shows the relative locations of the hospitals and sewage mains.

Wastewater Treatment Facility

The receiving facility for the municipal wastewater being investigated in this study is the Sims Bayou Sewage treatment plant. This plant has only recently been expanded to include a complete sludge drying process and post-treatment chlorination. Basically a conventional activated sludge municipal wastewater treatment facility by original design, the Sims Bayou plant retains that identity with the included expansions. The plant up-grading engineering projects have been undertaken due to the increased need for more advanced treatment facilities in the Houston area as well as the promulgation of new effluent standards, or requirements, by regulatory agencies for the Houston area.

The incoming raw municipal wastewater flow has recently been calculated to be 45 to 50 MGD, based on the mean value of a three month period. (See legend, Figure I-2). The raw incoming municipal wastewater contains 150-250 mg/l BOD and 150-250 mg/l suspended solids. Ten clarifiers are in operation. The percentage return sludge from those units is currently 100%. This sludge is returned to the aeration chambers. From those aeration units, approximately

560,000 gallons per day are piped to two sludge thickeners. The thickened sludge which is piped to the constant head sludge holding tank contains 2.5% - 3.5% (25,000 - 35,000 mg/l) suspended solids. Aeration tank (activated sludge units) suspended solids are maintained at 0.25% - 0.35% (2,500 - 3,500 mg/l). Sludge returned from clarifiers to the aeration tanks contains 0.5% - 1.2% (5,000 - 12,000 mg/l) suspended solids. Thickened sludge which is routed to the drying process contains 2.5% - 3.5% (25,000 - 35,000 mg/l) suspended solids. The pH is maintained between 7.0 and 8.5.

Insofar as upset conditions are concerned, a complete shutdown of the sludge drying facilities has not occurred in two years of operation. Prior to that time, one occurrence lasted for four hours, during which time 100% sludge recycle was initiated. The same procedure would be followed in the event of malfunction in the future. Due to the existance of a two circuit electrical bypass system, it is possible for the operation to stop the sludge feed volume to the sludge thickener clarifiers and utilize the holding tanks for solids retention until such time that the entire plant is returned to "normal" operation. During excessive rainstorms which significantly increase the infiltration inflow volume, if upset should occur, momentary shutdown is initiated. One such shutdown was reported, the duration of which was 15 minutes.

Figure I-2 shows a schematic diagram of the Sims Bayou Treatment Facility. Flow rates have been determined for normal operation, and a probabalistic model of detention time has been developed. It is calculated that the average detention time of the system is 21.73 hours, with a standard deviation of 8.76 hours. The time involved in processing the sludge after removal from the clarification tanks is short compared to the total detention time of the system.

The Discharge System

Figure I-3 graphically presents the average daily effluent discharge by month for 1974, along with the average daily tonnage of the flame-dried ash. Daily variation for a single month is given in figure I-4. Daily production of ash during the study period is presented in figure I-5.

The effluent is discharged into Sims Bayou, which joins the Houston Ship Channel a few hundred yards downstream. The Houston Ship Channel (see figure 10) has a flushing time of 38 days, and an estimated average flow rate at Sims Bayou of 120 mgd. The Ship Channel empties into Galveston Bay at Morgans Point, when the estimated average flow is 1,200 mgd. (Estimates provided by the Texas Water Quality Control Board.)

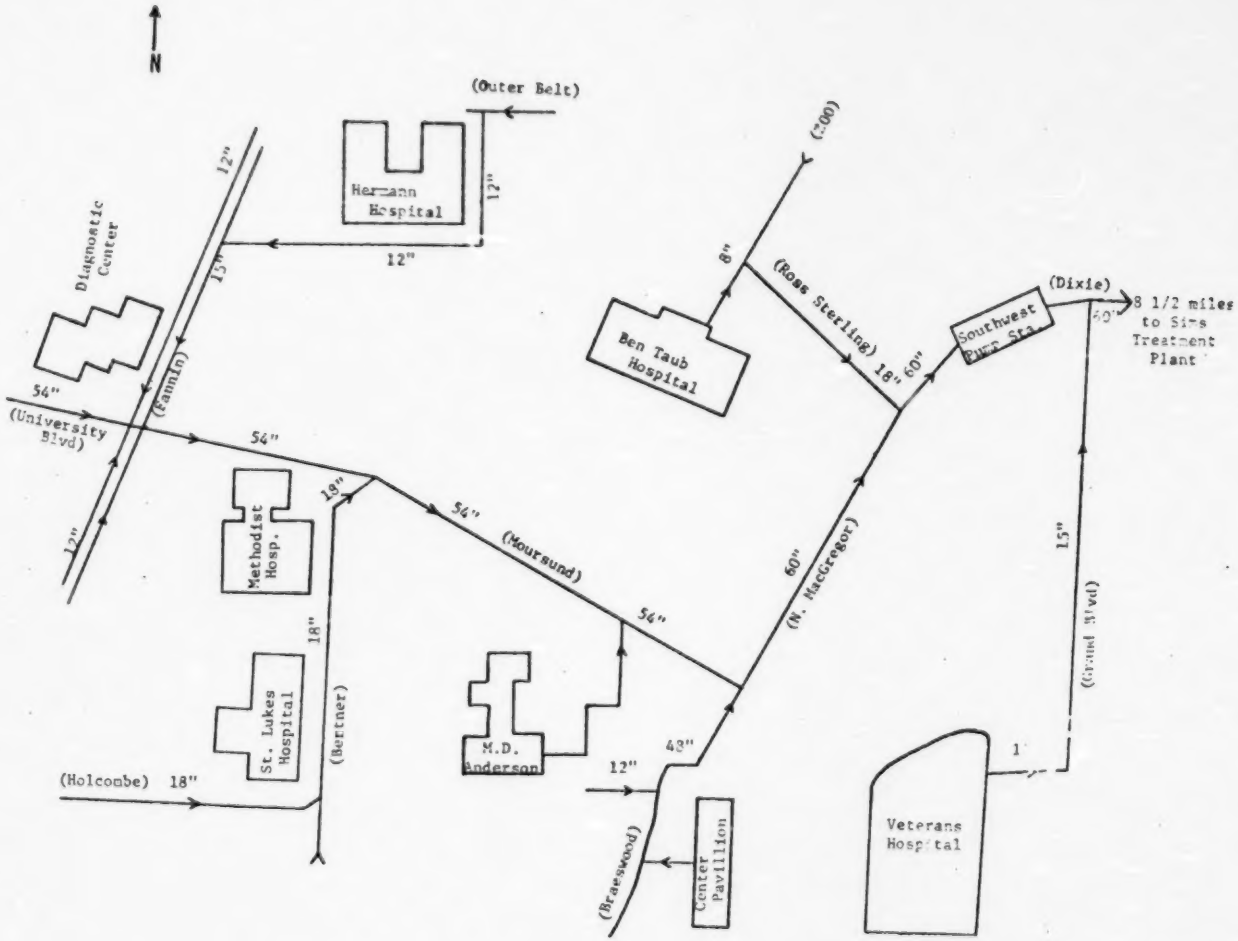

Figure I-1. Map of hospitals and sewer lines.

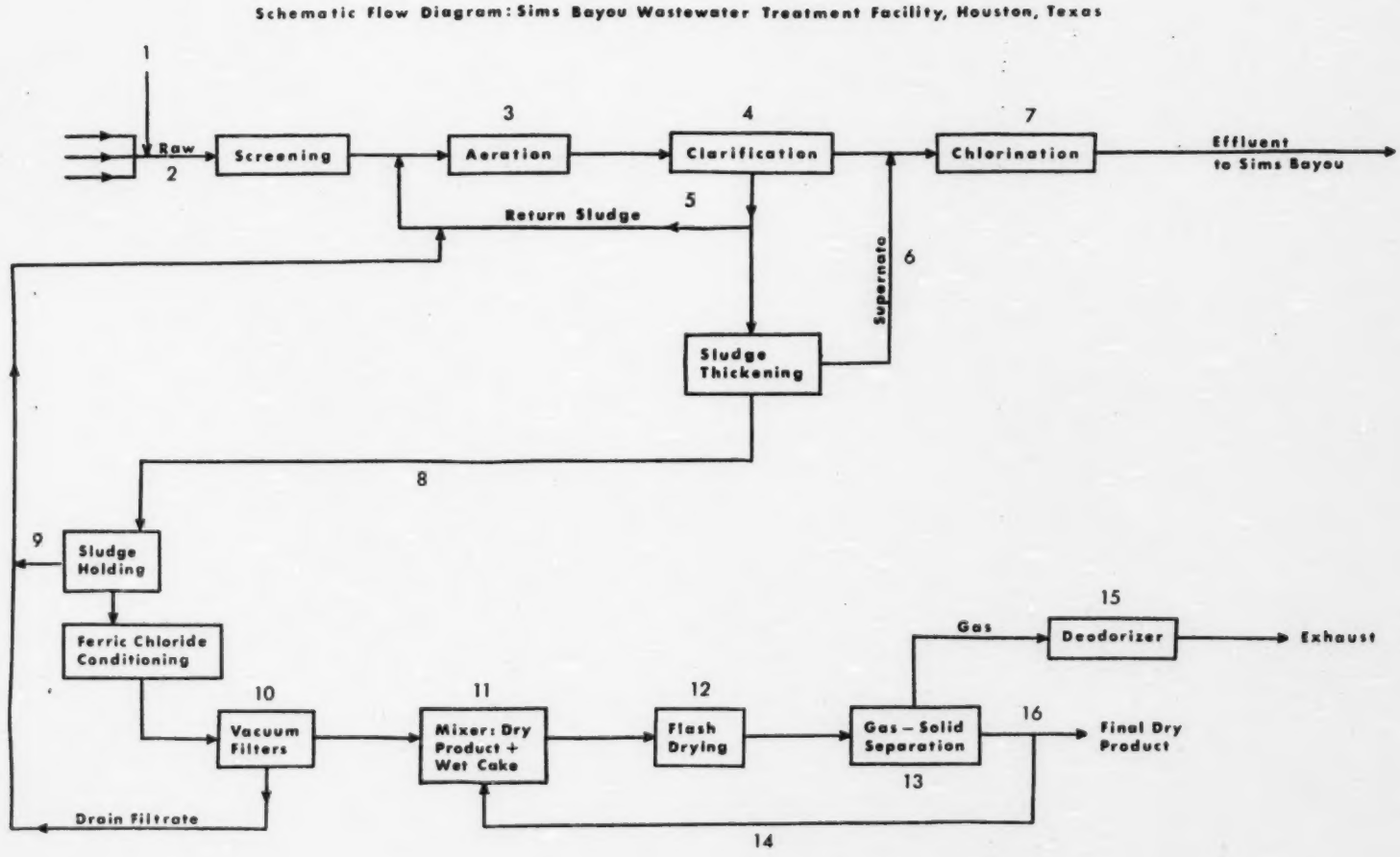

Figure I-2. Flow diagram of Sims Bayou Wastewater Treatment Facility.

General Hydraulic and Solids Data for Sims

Bayou Wastewater Treatment Plant; Houston, Texas

Diagram
Code No.

1. Sludge line from Northside will deliver approx. 400 Gpm(0.576 MGD) volume of secondary sludge having 5,000-12,000 mg/1 Susp. Solids. Inoperative through 5/10/74.
2. Raw municipal wastewater. Volume: 45-50 MGD, average. Diurnal flow variation: 35-60 MGD. Susp. Solids = 150-250 mg/1.B.O.D. = 150-250 mg/1.
3. Aeration Units (14 Activated Sludge Units) Susp. Solids in mixed liquor = 1,600 -4,500 mg/1. Detention time = 8-9 hours, avg. 14.52 MG. capacity.
4. Clarifiers. Detention time = 1-2 hours 5.23 MG volume.
5. Sludge Return. Recirculated volume based on a 60% dry weather flow rate. Return sludge Susp. Solids = 5,000-12,000 mg/1. Return through volume = 2.28 MG capacity.
6. Supernate from sludge thickeners. Volume = 2-5 MGD.
7. Chlorine contact chambers. Designed for 1-hour contact time. 1.5 mg/1 residual chlorine. 3-6 Gpm of 4-7% sodium hypochlorite solution used. 1.4 MG volume capacity.
8. Thickened sludge. Approx. 0.51 MGD volume. Approximate average Susp. Solids concentration = 2.5% (25,000 mg/1 (53.1 tons/d). Susp. solids range = 25,000 - 45,000 mg/1.
9. Overflow from sludge holding tank. Used only in event of dryer facility breakdown.

- Sludge holding tank has constant head. Sludge susp. solids = 30,000 mg/1.

Diagram Code

10. Vacuum filters. Rate = 200- 1,600 lbs. per filter hours. Wet cake produced is 80-85% water. Sludge produced = 175,000 mg/l Suspended Solids. Drain filtrate = 0.3-0.56 MGD.

11. Mixer. 85%-95% of the final dry product is returned for mixing with wet cake for conditioning prior to flash drying process. Mixed product has 22-26% water content.

12. Flash drying. Exposure time is 6-7 seconds at 1,000°-1,200°F.

13. Cyclone gas-solids separation. Temperature is 200°-225°F.

14. Dry product return volume = 85%-95% of total produced is returned to number 11.

15. Deodorizer. Run in furnace operation at approx. 1,200°F. Exhaust gases are at 500°-600°F.

    NOTE: Approx. 12,000 lbs. water per hour (34,532 GPD) lost through drying operation system.

16. Final dry product. 30-40 tons produced per day. Content: 6.1% water; 36.0% ash; 5.4% Nitrogen; 4.9% Available Phosphoric Acid; 4.0% Ferric Chloride.

August 1974 Data for Sims Bayou Wastewater Treatment Plant

Houston, Texas

Diagram Code Number	
2	231 mg/l suspended solids (40.1 tons/d) based on effluent to Sims Bayou of 41.7 MGD; 24 mg/l suspended solids (2.17 tons/d)
3	Aeration tanks det. time = 9.6 hrs. based on 41.7 MGD effluent and 14.52 MG capacity.
4	Clarifiers det. time = 3 hrs. based on 41.7 MGD effluent and 5.23 MG capacity.
5	Return line trough volume (capacity) = 2.28 MG. Det. time = 1.30 hrs. 60% volume recycled = 25 MGD.
7	Chlorine contact chamber(s) det. time = 0.8 hrs. based on 41.7 MGD effluent volume and 1.4 MG capacity.
-	Effluent = 41.7 MGD average; 24 mg/l suspended solids (2.17 tons/d) Avg. det. time through plant = 13.4 hrs. not accounting for recycle.
-	Sludge holding tank. Susp. Solids = 30,000 mg/d. Volume through = 0.777 MGD (97.2 tons/d)
16	Final dry product: 49.2 tons/d, 6.1% water content (3.0 tons/d or 719 gallons)
-	Avg. det. time of discrete particle based on probability analysis by Dr. T. Downs, 21.73 hours. Std. dev. of avg. det. time = 8.76 hrs.

Data courtesy of Mr. Rudy Sarich
Engineer, City of Houston

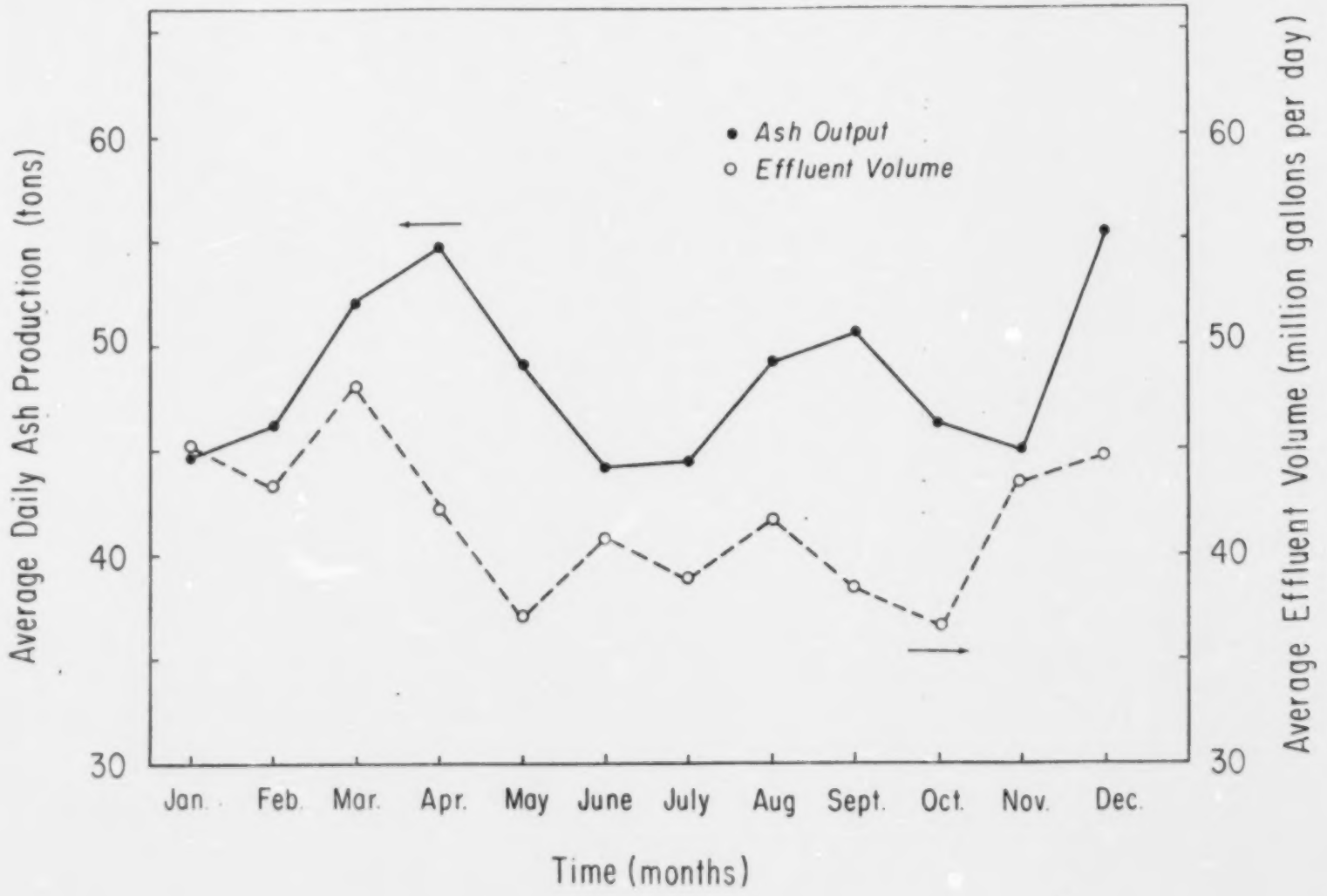

Figure I-3. Average daily ash production and effluent release from Sims Bayou Wastewater Treatment Facility.

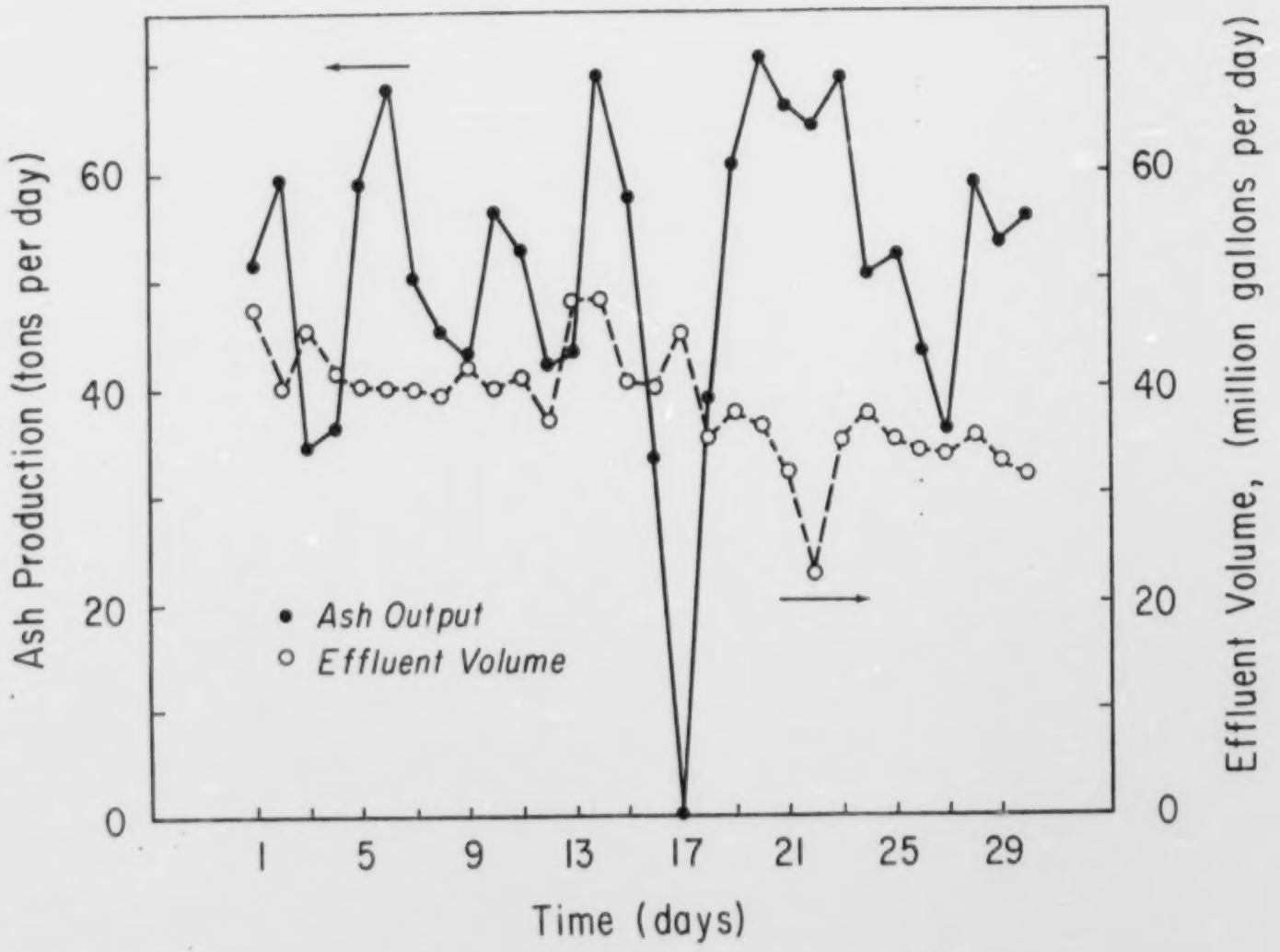

Figure I-4. Daily ash production and effluent release from Sims Bayou Wastewater Treatment Facility.

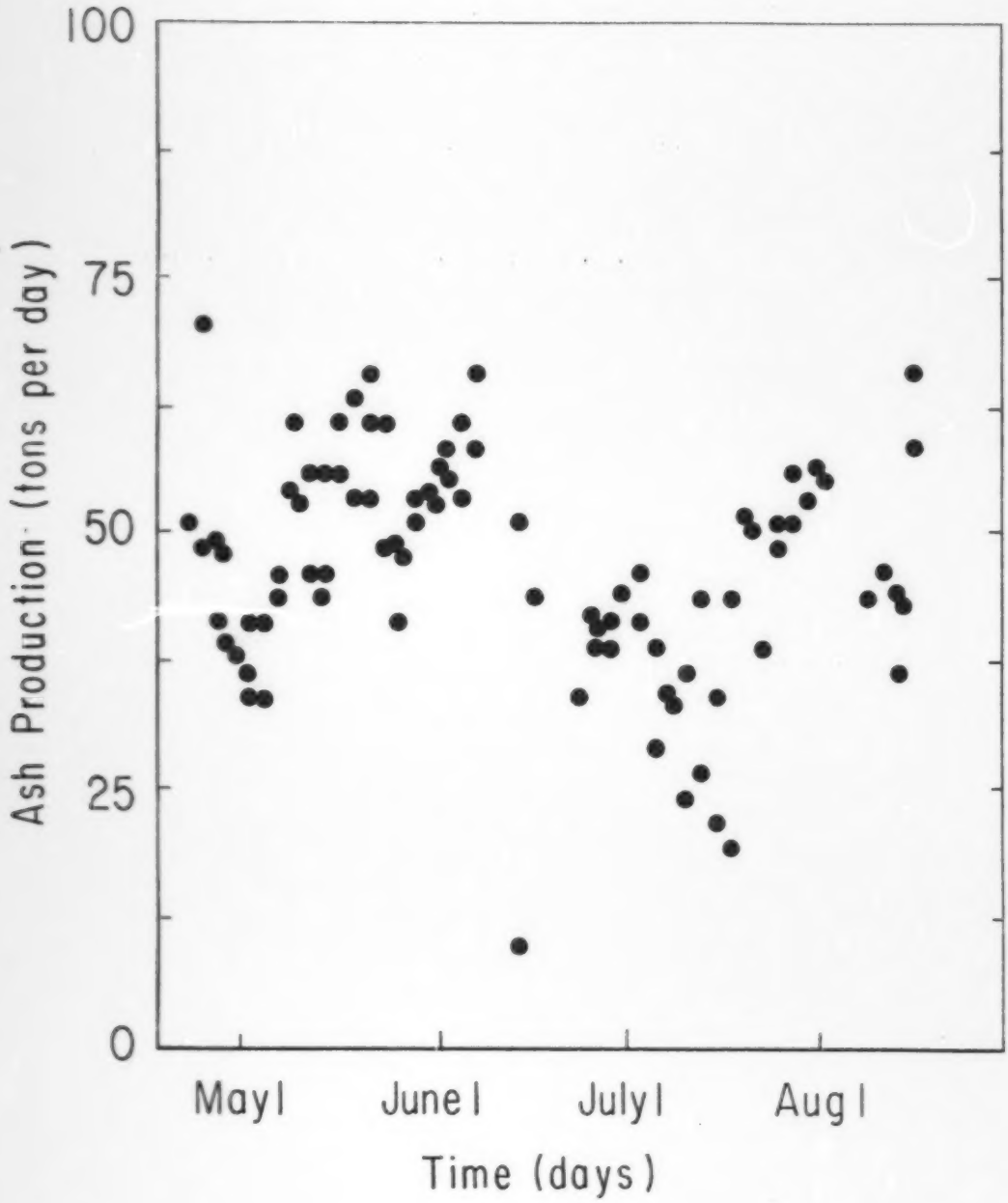

Figure I-5. Daily ash production from the Sims Bayou Wastewater Treatment Facility for the study period.

APPENDIX II

ENVIRONMENTAL MEASUREMENTS AND RELEVANT DATA FROM SIMS BAYOU TREATMENT FACILITY

Day Number (Day of Year)	Ash Activity (pCi/g ^{131}I)	Ash Output (tons per day)	^{131}I Release-Ash (μCi/day)	Total ^{131}I Release (μCi/day)
113.0	15.83	44.27	700.7	2999
114.0	16.26	44.22	718.8	3077
115.0	11.52	62.98	725.3	3104
116.0	9.870	42.96	424.0	1814
117.0	11.31	43.31	489.8	2096
118.0	15.58	36.11	562.4	2407
119.0	11.56	33.19	383.6	1643
120.0	8.267	34.85	288.1	1233
121.0	12.04	31.00	373.3	1597
122.0	18.76	28.38	532.3	2278
123.0	16.21	36.11	585.2	2505
124.0	17.63	35.23	621.0	2658
125.0	12.96	29.49	382.0	1635
126.0	11.21	37.54	420.6	1800
127.0	9.129	40.35	368.3	1577
128.0	7.853	48.41	380.0	1626
129.0	7.594	48.48	368.2	1575
130.0	6.284	54.82	344.5	1474
131.0	7.301	50.29	367.2	1572
132.0	24.52	41.23	1010	4323
133.0	18.35	38.57	707.7	3029
134.0	14.68	39.89	585.6	2506
135.0	15.94	49.01	781.1	3343
136.0	16.68	49.12	819.4	3507
137.0	19.39	53.71	1042	4459
138.0	17.47	47.06	822.4	3520
139.0	15.02	56.50	848.3	3631
140.0	13.55	58.33	790.4	3383
141.0	11.29	47.57	537.2	2299
142.0	11.45	54.11	619.4	2651
143.0	9.542	54.08	516.0	2209
144.0	8.086	42.84	346.4	1483
145.0	7.715	36.34	280.4	1200
146.0	7.361	42.28	311.3	1332
147.0	5.060	42.47	214.8	919.7
148.0	4.784	47.39	226.7	970.3
149.0	4.362	45.06	196.5	841.1
150.0	4.879	47.00	229.4	981.4
151.0	27.51	48.08	1323	5658
152.0	8.137	50.80	413.5	1769
153.0	7.801	52.49	409.4	1752
154.0	8.370	49.54	414.7	1775
155.0	8.680	48.23	418.7	1792
156.0	9.706	53.34	517.7	2216
157.0	28.91	58.57	1693	7246
158.0	15.72	52.22	821.0	3514

Day Number (Day of Year)	Ash Activity (pCi/g ^{131}I)	Ash Output (tons per day)	^{131}I Release-Ash (μCi/day)	Total ^{131}I Release (μCi/day)
165.0	67.13	7.374	495.0	2118
166.0	63.22	45.62	2884	12343
167.0	52.06	37.69	1963	8401
175.0	19.98	30.44	608.2	2603
176.0	21.96	34.26	752.1	3219
177.0	21.99	37.02	814.2	3485
178.0	24.58	36.38	894.4	3828
179.0	24.39	37.08	904.2	3870
180.0	22.64	34.14	772.9	3307
182.0	20.17	38.10	768.6	3290
183.0	18.27	39.00	712.6	3050
184.0	19.05	40.14	764.8	3274
185.0	18.45	36.88	680.2	2912
186.0	23.27	25.26	587.9	2516
187.0	24.65	33.09	815.7	3491
189.0	26.29	30.61	804.8	3444
190.0	26.46	29.43	778.8	3333
191.0	25.00	31.30	782.5	3349
192.0	19.31	21.01	405.6	1735
193.0	20.34	23.47	477.5	2044
194.0	25.52	39.16	999.5	4278
196.0	18.27	18.14	331.6	1419
197.0	18.79	28.75	540.3	2312
198.0	16.47	15.71	258.8	1108
199.0	14.15	38.80	548.8	2349
200.0	41.48	44.94	1864	7978
202.0	50.48	44.59	2251	9635
204.0	17.42	34.65	603.6	2584
206.0	18.82	42.33	796.5	3410
207.0	23.87	45.78	1093	4677
208.0	27.97	45.42	1271	5440
209.0	17.68	49.96	883.2	3780
211.0	49.66	47.23	2346	10041
212.0	51.43	49.33	2537	10858
213.0	42.32	49.88	2111	9035
221.0	23.10	39.36	909.7	3893
222.0	27.07	41.72	1129	4832
224.0	71.89	32.33	2324	9947
225.0	180.4	37.88	6833	29245
226.0	157.1	38.66	6074	25997
227.0	114.9	51.35	5900	25252
228.0	77.49	59.93	4644	19876

APPENDIX III

CALIBRATION DATA

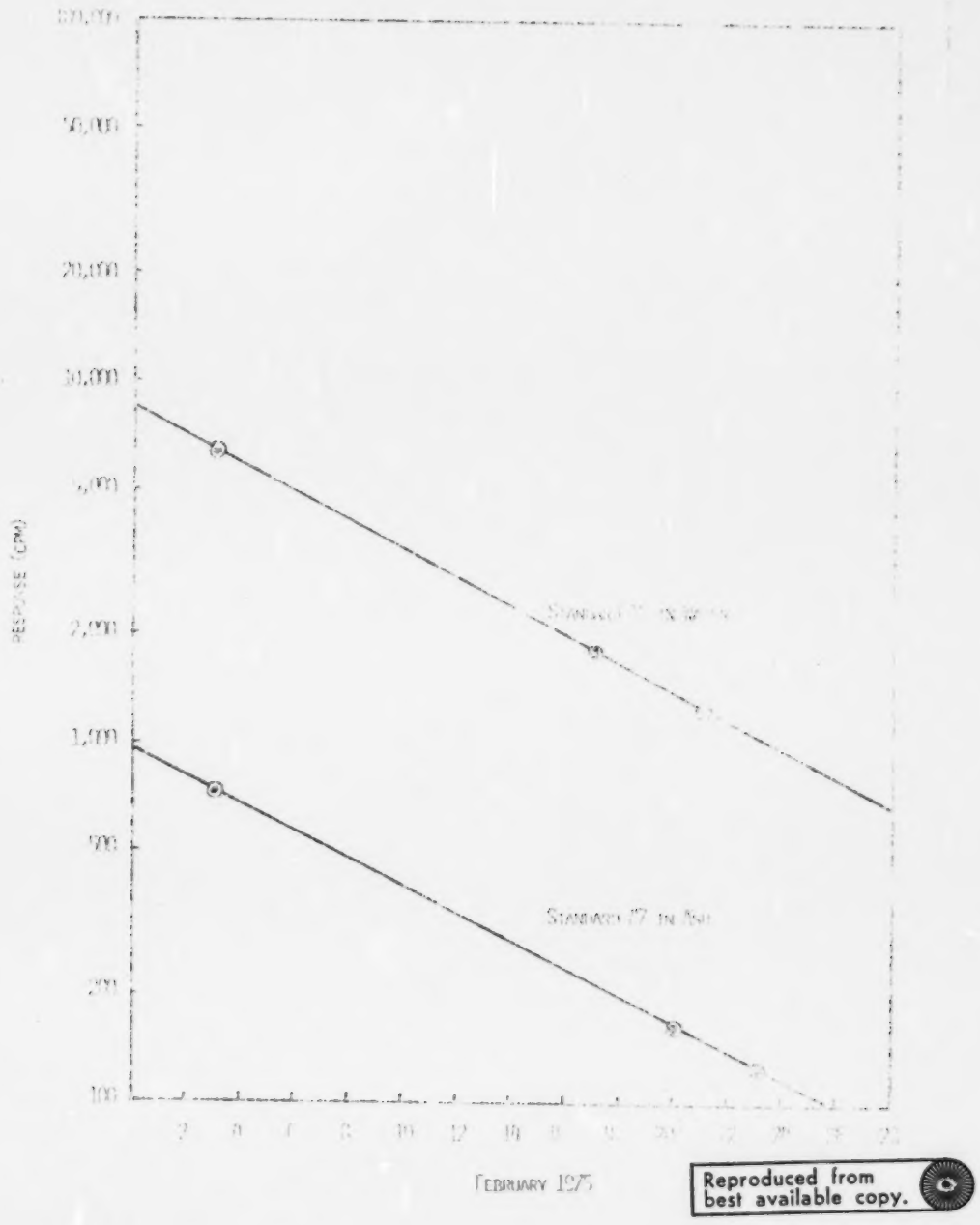

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Figure III-1. Instrument response in counts per minute under the photopeak for ^{131}I standards for two sample media.

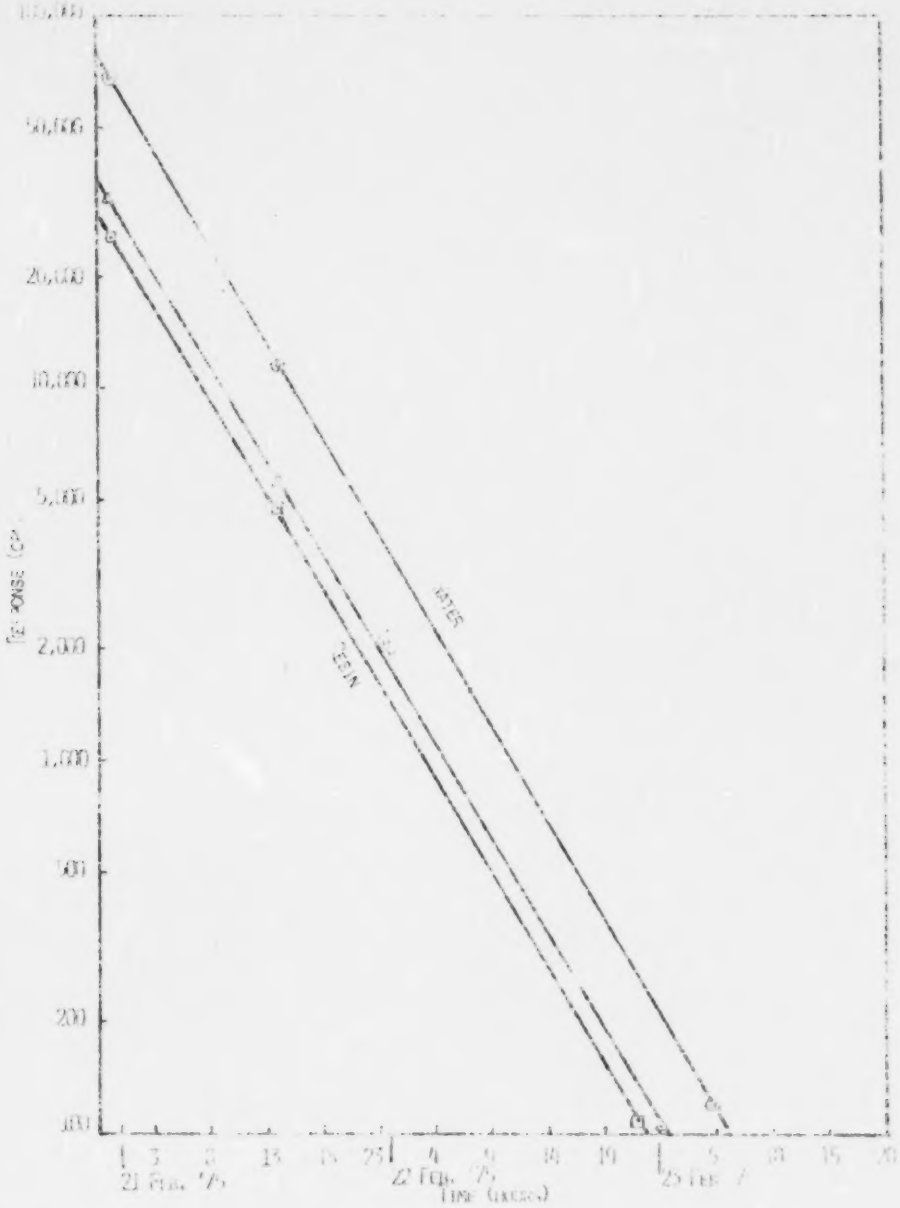
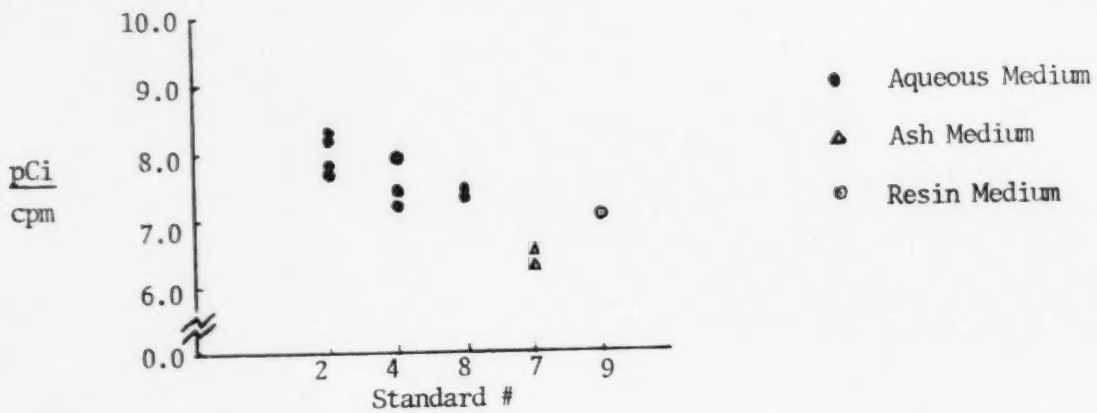


Figure III-2. Instrument response in counts per minute under the photopeak for ^{99m}Tc for three sample media.

CALIBRATION CONSTANTS
(pCi/g per cpm)

Isotope	H_2O	Ash	Resin
^{131}I	7.70	6.40	7.05
^{99m}Tc	8.18	7.40	8.70

Agreement Among ^{131}I Calibration Standards



Minimum Detectable Activity

The minimum detectable activity will be taken to be that activity level which will produce a residual count rate in excess of two standard deviations above the background in the photopeak for the medium being investigated. The standard deviation is calculated by the relation:

$$\sigma_n = \sqrt{\frac{r_g}{t_g} + \frac{r_{bg}}{t_{bg}}}$$

where r_g is the gross count rate, r_{bg} is the background count rate, t_g and t_{bg} are the gross and background count times, respectively, and σ_n is the standard deviation of the net counting rate. In all work in this study, $t_g = t_{bg}$, and for minimum detectable activity, $r_g \doteq r_{bg}$. Hence,

$$\sigma_n = \sqrt{2r_{bg} / t_{bg}}$$

The majority of samples analysed for this project were counted for 100 minutes. With t_{bg} = 100 minutes, minimum detectable activities were computed for the various media:

	Flame-Dried Ash	Aqueous (i.e, sludge)	Resin
r_{bg}	58 cpm	25 cpm	36 cpm
Typ. Sample Size	90 grams	100 grams	40 liters
Calibration Factor	6.40 pCi/cpm	7.70 pCi/cpm	7.05 pCi/cpm
Min. Det. Activity	0.15 pCi/g	0.11 pCi/g	0.30 pCi/l

APPENDIX IV

HOSPITAL DATA

RADIONUCLIDE USAGE BY CO-OPERATING INSTITUTIONS

CODE FOR TABLES OF RADIONUCLIDE USAGE

Nuclide 099 = Tc99m

075 = Se75

Month/year example 10/73

Doses are in millicuries

Day = Day of the month

Chemical form:

5 Human Serum Albumin

12 Technetium Heptasulfide

13 Colloid

15 Sodium Pertechnetate

17 Macroaggregated Albumin

24 DTPA

25 Iron Ascorbate Complex

26 Tin-polyphosphate

27 Tin-pyrophosphate

28 Tin hydroxide

29 Iron hydroxide

30 EDTA

HOW TO READ A TABLE OF RADIONUCLIDE USAGE

For each day of the month there are two lines for each chemical form. On the first line will be the total number of patients for this isotope and chemical form done in all study hospitals on the given day of the month.

On the second line, one will find the total activity of the radionuclide used in this particular chemical form.

For example:

Nuclide 99

Month 10/73

Day	Chemical form 12
1	14
	4.05E + 01

Fourteen patients administered technetium heptasulfide on 1 October 73 for a total activity used of $4.05 \times 10^{+1}$ or 40.5 mCi. At the bottom of each chemical form column, the total activity used in each chemical form for the entire month will be given.

To the far right of the table, the last column is the daily total of all activity used of the radionuclide for which the table was made. The last number of the last column, that is the number in the lower right hand corner of the table, is the total activity used for the entire month in all chemical forms.

EXAMPLE

NUCLIDE 99
MONTH 10/7a
DOSES ARE IN MILLIREMS

DAY	EMISSION FROM ...																									
1																										
2																										
3																										
4																										
5																										
8																										
9																										
10																										
11																										
12																										
15																										
16																										
17																										
18																										
19																										
22																										
23																										
24																										
25																										
26																										
29																										
30																										
31																										
1-31																										

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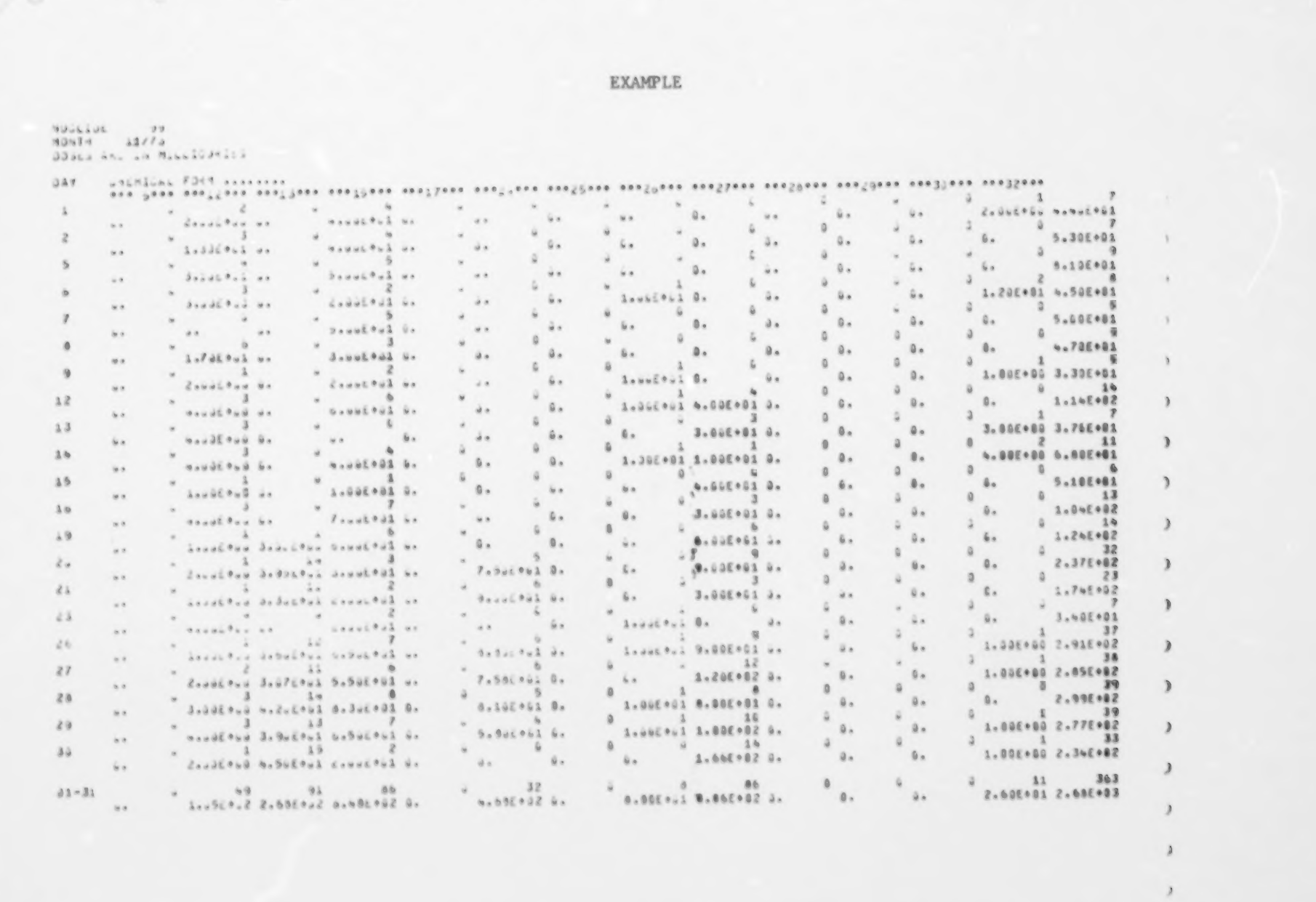
EXAMPLE



NOTE: Because of its length, the complete Table of Radionuclide Usage is not included in this volume.

DAILY EXCRETION OF ^{131}I AND CALCULATED ^{131}I DISCHARGE FROM SIMS BAYOU PLANT

(For Days When Both Sets of Data are Available)

Day #	I-131 Excretion mCi	Sims I-131 Discharge mCi
114.	5.26	3.077
115.	145.58	3.104
116.	5.72	1.814
117.	.35	2.096
118.	.16	2.407
119.	.01	1.643
120.	0.00	1.233
121.	.28	1.597
122.	.25	2.278
123.	.45	2.505
124.	.85	2.658
125.	.44	1.635
126.	.37	1.800
127.	.01	1.577
128.	.07	1.626
129.	7.61	1.575
130.	4.57	1.474
131.	4.24	1.572
132.	.76	4.323
133.	.02	3.029
134.	0.00	2.506
135.	3.74	3.343
136.	.21	3.507
137.	.35	4.459
138.	.20	3.520
139.	.25	3.631
140.	.01	3.383
141.	0.00	2.299
142.	0.00	2.651
143.	.60	2.209
144.	.22	1.483
145.	.37	1.200
146.	.23	1.332
147.	.01	.920
148.	0.00	.970
149.	0.00	.841
150.	.35	.981
151.	.20	5.658
152.	5.89	1.769
153.	1.04	1.752
154.	276.83	1.775
155.	10.00	1.792
156.	69.41	2.216
157.	5.00	7.246
158.	.85	3.514
165.	.19	2.118
166.	.01	12.340
167.	.32	8.401
175.	.02	2.603
176.	0.00	3.219
177.	.17	3.485
178.	.64	3.828
179.	.02	3.870
180.	69.41	3.307
181.	7.49	3.300
182.	.18	3.290
183.	.07	3.050
184.	.21	3.274
185.	.13	2.912

APPENDIX V

HOSPITAL DATA COLLECTION INFORMATION AND REFERENCES

THE UNIVERSITY OF TEXAS
HEALTH SCIENCE CENTER AT HOUSTON
SCHOOL OF PUBLIC HEALTH

713 792 2121

P.O. BOX 20186
HOUSTON, TEXAS 77025

Dear

In cooperation with the Texas State Department of Health, Division of Occupational Health and Radiation Control and pursuant to a research contract between The University of Texas School of Public Health and the United States Environmental Protection Agency, the contribution of radioactivity by the Texas Medical Center and surrounding institutions to the sewage at the Sims Bayou Sewage Treatment Plant in Houston is being studied.

As a portion of this study, the records of all radioactive materials licensees located on this sewage treatment plant are being reviewed to first determine what if any waste is being disposed of through the sewer system and second to determine the radiopharmaceuticals used and patient loads of each nuclear medicine department.

All information obtained in this study, as well as the results of the study will in no way be identifiable with any institution or person. Each licensee will be given a code identification which will be known only to that institution and the senior investigator.

In the coming weeks, you will be contacted by personnel of The University of Texas and the State Health Department in order to set up an appointment for a visit to your institution to obtain the necessary information. Your cooperation with this study will be deeply appreciated.

Should you have any questions concerning the study, please don't hesitate to contact me at 792-4321.

Sincerely,

Thomas F. Gesell, Ph.D.
Assistant Professor of Health Physics
and Director, Nuclear Medicine
Environmental Discharge Measurement

TFG/dlr

Information on Patients

Surname
1 2 3 4 5 6 7 8 9

Patient Number
10 11 12 13 14 15 16 17 18

Birth Year
19 20

Sex
21

Race
22

Study
23 24

Nuclide Used
25 26 27 28 29 30

Chemical Form
31 32 33

Physical Form
34

Administration Pathway
35

Instrument Used
36

Dose
37 38 39 40

Unit of Dose
41

Time of Administration
42 43 44 45

In-patient Date of Admissions
46 47 48 49 50 51

In-patient Discharge Date
52 53 54 55 56 57

Date of Test
58 59 60 61 62 63

Results of Test
64

Hospital Code
65 66

Information on Patients, (Continued)

Information Code

Surname - no code

Birth Year - no code

Sex - 1 male
2 female
3 unknown

Race - 1 Caucasion
2 Negroid
3 Mongoloid

Use of Activity - 1 Thyroid uptake
2 Renogram
3 Thyroid scan
4 Biliary Patency Study
5 Perfusion Lung Scan
6 CSF Flow Study
7 Hyperthyroidism (therapy)
8 Thyroid Cancer (therapy)
9 Plasma volume
10 Fat absorption studies
11 T-3 uptake
12 T-4 uptake
13 Spleen scanning
14 Liver scan
15 Salivary gland scan
16 Cardiac blood pool scan
17 Brain scan
18 Broncial patency scan
19 Cerebral blood flow
20 Renal blood flow study
21 Red Blood cell mass
22 RBC Survival & Sequestration
23 Platelet Survival & Sequestration
24 GI protein loss study
25 GI blood loss study
26 Vitamin B-12 absorption
27 Ferrokinetic studies
28 Parathyroid localization
29 Pancreas scan
30 Lymph node scan
31 Malignant Effusions (Peritoneal)
32 Malignant Effusions (Pleural)
33 Myocardial scan
34 Ventilation (Lung Scans)
35 Perfusion (Lung Scans)
36 Renal Scanning
37 Bone Scan
38 Polycythemia (Therapy)
39 Bone Metastases (Therapy)

Nuclide Used - First 3 spaces are for atomic number of element
Second 3 spaces are for atomic weight of the isotope

Chemical form - 1 Triiodothyronine
2 Thyroxine
3 Vitamin B-12
4 Sodium Chromate
5 Human Serum Albumin
6 Ferrous Citrate
7 Triolein
8 Oleic Acid
9 Chromium Chloride
10 Hippuran
11 Selenomethionine
12 Technetium Heptasulfide
13 Colloid
14 Rose Bengal
15 Sodium Pertechnetate
16 Cesium Chloride
17 Macroaggregated Albumin
18 Gas
19 Chlormerodrin
20 Strontium Nitrate
21 Sodium Iodide
22 Sodium Phosphate
23 Chromic Phosphate
24 DTPA
25 Iron Ascorbate Complex
26 Tin-polyphosphate

Information on Patients (Continued)

Information Code

Chemical form (continued) - 27 Tin pyrophosphate
28 Tin hydroxide coprecipitate
29 Iron hydroxide coprecipitate
30 EDTA
31 Chloride

Physical Form - 1 Solid
2 Liquid
3 Gas

Administration Pathway - 1 GI
2 IV
3 Pul

Instrument Used - 1 Camera
2 Scanner
3 Well Counter

Dose - no code

Unit of Dose - 1 MCi
2 µCi
3 NCi

Inpatient Date of Admission - Columns 46 and 47 - month

01 January	07 July
02 February	08 August
03 March	09 September
04 April	10 October
05 May	11 November
06 June	12 December

Columns 48 and 49 - day of month
01 through 31

Columns 50 and 51 - year 73 or 74

Inpatient Discharge Date - Columns 52 and 53 - month

01 January	07 July
02 February	08 August
03 March	09 September
04 April	10 October
05 May	11 November
06 June	12 December

Columns 54 and 55 - day of month
01 through 31

Columns 56 and 57 - year 73 or 74

Information on Patients (continued)

Information Code

Date of Test - Columns 58 and 59 - month

01 January	07 July
02 February	08 August
03 March	09 September
04 April	10 October
05 May	11 November
06 June	12 December

Columns 60 and 61 - day of month
01 through 31

Columns 62 and 63 - year 73 or 74

Results of Test - 1 Normal
2 Diseased
3 Equivocal

Hospital Code - Columns 65 and 66
02 Center Pavilion
04 Hermann Professional Bldg. (Medical Center)

25 M. D. Anderson

Patient Status (In or Out Patient) - Column 67
1 In patient
2 Out patient
3 Unknown

The Claridge and Kendrick Excretion Model

Concentrations in sewage are confounded by the problems of how much is excreted, in what way and when. Inasmuch as we are primarily interested in total activity and average concentrations, the problem is somewhat simpler than predicting peak concentrations during a day.

Claridge and Kendrick* reviewed the problem and proposed a mathematical model which is applicable to this study. In their review, they began with the classical non-radioactive drug excretion model.

$$M_p = M_D e^{-\lambda_b t} \qquad (1)$$

where

M_D is the dose administered

M_p is the dose remaining in the patient after time t

λ_b is the biological half life

Thus the amount excreted, M_E, simply equal to $M_D(1-e^{-\lambda_b t})$. (2)

There is frequently a portion of any dose which is virtually permanently deposited in the body so that there may actually be an amount of drug, less than the total administered, which can be available for excretion. Call this quantity F, the fraction of the original dose available for excretion. Now then, if you multiply M_D by F, you have the quantity of drug available for excretion and equation (2) becomes

$$M_E = FM_D\ (1-e^{-\lambda_b t}) \qquad (3)$$

In order to determine the activity excreted instead of the chemical quantity, we would simply multiply by the specific activity (mCi/mg) so that equation (3) becomes

$$A_E = SM_E \tag{4}$$

Assuming a very long radioactive half life and a short (t) time.

In the case of the shorter half life radionuclides, we must also consider their half lives since t is usually long compared to the radioactive half life.

These equations have told only the total quantity of material either chemical or radioactive which is excreted in time t. If we want to know the rate we must differentiate equation (3) with respect to time

$$\underline{M}_E = \frac{dM_E}{dt} = FM_D\lambda_b e^{-\lambda_b t} \tag{5}$$

When the time t is long compared to the radioactive half life, an additional correction for radioactive decay must be made.

$$\underline{A}_E = SFM_D\lambda_b e^{-\lambda_b t}\ e^{-\lambda_r t} \tag{7}$$

where λ_r = radioactive decay constant.

Equation (7) then may be reduced to

$$A_E = FA_D\lambda_b e^{-(\lambda_b+\lambda_r)t} \tag{8}$$

where $A_D = SM_D$ or Activity in original dose administered.

Claridge and Kendrick considered the daily group of patients given doses to be receiving them as a compartment. Thus, they characterized the input, i, to the patient compartment in terms of patients and dose for every time period τ. Input is then

$$i = \frac{NA_D}{\tau} \tag{9}$$

Where N is the number of patients administered dose A_D in time τ.

To obtain the average excretion rate, one must take the integral of the excretion rate and multiply by the frequency of administration.

$$\overline{A}_E = \frac{N}{\tau}\int_0^\infty A_E\,dt \qquad (10)$$

or $$\overline{A}_E = \frac{N}{\lambda} F A_D \left(\frac{\lambda_b}{\lambda_b+\lambda_r}\right)$$

The model becomes more complicated by the fact that there is not just one λ_b or one F but perhaps several; one for each excretion pathway. Fortunately, however, for our purposes of evaluating the contribution of nuclear medicine patient to the activity in sewage, most other modes of excretion such as perspiration and ventilation may be ignored. Considering only urinary and fecal excretion in the pathways to sewage activity, the equation may then be expressed as

$$A_E = (F_u + F_f)A_D e^{-\lambda_r t}\left[f - \frac{F_u}{F_u+F_f}\,e^{-\lambda_u t} - \frac{F_f}{F_u+F_f}\,e^{-\lambda_f t}\right]$$

for total activity excreted

and $$\overline{A}_E = \frac{N}{\tau} A_D (F_u+F_f)\left[\left(\frac{F_u}{F_u+F_f}\right)\left(\frac{\lambda_u}{\lambda_u+\lambda_r}\right) + \left(\frac{F_f}{F_u+F_f}\right)\left(\frac{\lambda_f}{\lambda_u+\lambda_r}\right)\right]$$

for the average excretion rate.

Excretion Data Summary *

Isotope	Form	Administration	F_μ	λ_μ	F_ε	λ_ε
Tc99m	TcO_4	IV	0.4	2.303	0.2	0.921
Tc99m	TcO_4	Oral	0.225	2.303	0.5	0.921
Tc99m	Serum Aluminum	IV	0.5	0.005	0.5	0.005
Tc99m	Tc_2O_7	IV	0.5	0.06	-	-
I-131	NaI	IV	0.9	3.55	-	-
I-131	NaI	IV	0.67	2.9	-	-
Hg-203	Neokydrin	IV	0.571	4.7	-	-

*From Claridge and Kendrick

Radiopharmaceutical Excretion Bibliography

Adetepe, M. H. and E. J. Potchen, "In 113 Microcolloid - An Optimal Radiopharmaceutical for Liver and Spleen Scanning (Abstract)," J. Nucl. Med., 9, 298 (1968).

Alexander, W. D., D. A. Koutras, J. Crooks, W. W. Buchanan, E. M. MacDonald, M. H. Richmond and E. J. Wayne, "Quantitative Studies of Iodine Metabolism in Thyroid Disease," Quart. J. Med., 31, 281 (1962).

Andrews, G. A., "Treatment of Thyroid Carcinoma with Radioactive Iodine", J. Kansas M. Soc., 54, 7-10 (1953).

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APPENDIX VI

OUTPUT FROM COMPUTER CODE AIREM FOR THE RELEASE OF 60 Ci/YR OF ^{133}Xe FROM THE TEXAS MEDICAL CENTER

DIST	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.72	1.18	1.36	1.44	1.91	2.87	2.55
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.51	0.35	0.47	0.43	0.46	0.84	0.78
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.28	0.19	0.26	0.24	0.25	0.49	0.43
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.18	0.13	0.17	0.16	0.17	0.33	0.28
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.13	0.09	0.13	0.12	0.12	0.24	0.21
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.09	0.06	0.08	0.08	0.08	0.16	0.14
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.06	0.04	0.06	0.05	0.05	0.11	0.09
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.04	0.03	0.04	0.04	0.04	0.08	0.06
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.03	0.02	0.03	0.03	0.03	0.06	0.05
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.02	0.02	0.03	0.02	0.02	0.05	0.04
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.02	0.02	0.02	0.02	0.02	0.04	0.03

POPULATION DOSE IN THE INDICATED COMPASS SECTOR AND ANNULAR RING (MAN-REM)
AVERAGED TO CONFORM TO THE POPULATION WHEEL WIND SECTORS
FOR THE ESTIMATED POPULATION

DIST	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	RUNNING TOTAL
1.00	[illegible]	[illegible]	[illegible]	0.01	0.01	[illegible]	0.00	0.00	[illegible]	0.03	0.03	0.02	0.07	0.21	1.43	1.28	6.96
2.00	[illegible]	[illegible]	[illegible]	0.22	0.23	[illegible]	0.09	0.23	[illegible]	0.49	0.06	0.58	1.23	0.29	1.09	1.38	15.35
3.00	[illegible]	[illegible]	[illegible]	0.35	0.35	[illegible]	0.14	0.0	0.08	0.00	0.00	0.05	0.27	0.48	0.54	0.96	1.87	23.36
4.00	[illegible]	[illegible]	[illegible]	0.66	0.24	[illegible]	0.25	0.33	0.02	[illegible]	0.00	0.21	0.44	0.69	0.42	0.63	1.72	31.17
5.00	[illegible]	[illegible]	[illegible]	0.62	0.17	[illegible]	0.27	[illegible]	0.15	[illegible]	0.00	0.15	0.70	0.53	0.46	0.82	1.12	38.34
7.00	[illegible]	[illegible]	[illegible]	0.55	0.29	[illegible]	0.54	[illegible]	0.63	[illegible]	0.06	0.63	0.67	0.80	0.47	1.16	1.23	48.57
[illegible]	[illegible]	[illegible]	[illegible]	0.51	[illegible]	[illegible]	[illegible]	0.43	[illegible]	0.35	0.39	1.41	1.09	0.75	0.51	0.86	59.86
[illegible]	[illegible]	[illegible]	[illegible]	0.23	1.31	[illegible]	[illegible]	[illegible]	[illegible]	0.53	0.33	0.71	0.65	0.52	0.55	1.10	68.40
15.00	[illegible]	[illegible]	[illegible]	0.12	[illegible]	[illegible]	0.03	0.01	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
17.00	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.0	0.01	0.04	0.16	0.54	0.81	0.52	79.14
20.00	[illegible]	[illegible]	[illegible]	0.09	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

THE CONTRIBUTING RADIONUCLIDES ARE

[illegible]	CRITICAL ORGAN	DOSE	CURIES RELEASED	DECAY CONSTANT (1/SEC)	DECON FACTOR
XE-133	WB	2[illegible]	0[illegible].000	0.15E-05	1.00
	TOTAL CI=		.000E+05		

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DOSE TO AN INDIVIDUAL IN THE INDICATED COMPASS SECTOR AND ANNULAR RING (MREM)

DIST		N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
.4500	.50	2.63	2.63	4.47	2.12	4.81	1.62	2.52	4.30	3.54	2.39	3.41	2.55	3.00	3.36	5.45	
1.2500	.75	1.40	1.71	1.87	.99	2.56	0.97	1.01	1.75	1.50	1.03	1.40	1.68	1.37	2.67	2.32	
2.4500	1.50	.73	.98	.92	.25	.82	0.32	0.52	1.16	0.77	0.54	0.74	0.87	0.71	1.41	1.19	
35.0000	2.50	.48	.59	.82	.10	.31	0.19	0.32	0.64	0.48	0.34	0.47	0.46	0.45	0.90	0.75	
4.4500	3.50	.32	.41	.15	.11	.13	0.13	0.23	0.45	0.34	0.24	0.33	0.30	0.31	0.63	0.52	
5.4500	4.50	.24	.31	.10	.07	.09	0.09	0.14	0.28	0.21	0.15	0.21	0.19	0.20	0.40	0.33	
6.4500	5.50	.19	.24	.07	.05	.07	0.05	0.09	0.17	0.13	0.09	0.13	0.12	0.14	0.25	0.20	
7.4500	6.50	.15	.19	.05	.04	.05	0.04	0.06	0.12	0.09	0.06	0.09	0.08	0.09	0.17	0.14	
11.4500	9.00	.09	.11	.03	.02	.03	0.02	0.04	0.07	0.05	0.04	0.05	0.05	0.05	0.10	0.08	
13.4500	11.00	.07	.08	.02	.02	.02	0.01	0.03	0.05	0.04	0.03	0.04	0.03	0.04	0.07	0.06	
15.4500	13.00	.05	.06	.02	.01	.02	0.01	0.02	0.04	0.03	0.02	0.03	0.03	0.03	0.05	0.04	
17.4500	15.00	.04	.05	.01	.01	.01	0.01	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.04	0.03	
19.4500	17.00	.04	.04	.01	.01	.01	0.01	0.01	0.02	0.02	0.01	0.02	0.02	0.02	0.03	0.03	

POPULATION DOSE TO THE INDICATED COMPASS SECTOR AND ANNULAR RING (MAN-REM)
AVERAGED TO CONFORM TO THE POPULATION SMEAR RING SECTORS
FOR THE ESTIMATED POPULATION

DIST		N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	RUNNING TOTAL
1.000	0.50	0.11	0.00	0.03	0.02	0.00	0.12	0.02	0.03	0.00	0.00	1.19	1.71	0.02	2.68	2.73	13.99	
2.000	1.50	1.05	1.34	0.00	0.07	0.33	0.24	0.67	1.44	1.44	0.17	1.72	3.62	0.83	3.28	4.11	38.74	
3.000	2.50	1.35	2.05	1.00	0.99	0.41	0.0	0.23	0.17	0.00	0.14	0.77	1.35	1.53	2.77	5.24	61.38	
4.000	3.50	1.00	1.72	1.77	0.03	0.72	0.09	0.05	0.01	0.01	0.57	1.10	1.05	1.13	1.71	4.55	82.29	
5.000	4.50	1.09	1.92	1.62	0.04	0.71	0.09	0.30	0.02	0.01	0.38	1.02	1.37	1.00	2.14	2.84	100.73	
7.000	5.50	0.79	1.19	1.34	0.72	1.11	1.34	1.50	0.14	0.14	1.53	2.13	1.94	1.14	2.87	2.92	125.64	
11.000	8.00	0.70	1.10	1.10	0.72	0.97	0.99	0.99	0.14	0.80	0.90	3.68	2.91	1.71	1.19	1.94	151.00	
13.000	10.00	0.53	2.13	0.53	0.71	0.55	0.04	0.14	0.61	1.17	0.73	1.90	1.40	1.19	1.24	2.39	170.72	
15.000	12.00	1.07	0.72	0.44	0.26	0.11	0.00	0.02	0.04	0.28	0.28	0.30	1.09	0.40	3.04	2.31	184.53	
17.000	14.00	1.27	1.49	0.41	0.33	0.20	0.09	0.05	0.06	0.0	0.03	0.08	0.35	1.20	1.76	1.07	193.90	
19.000	16.00	1.30	1.30	0.19	0.02	0.30	0.09	0.13	0.0	0.00	0.08	0.04	0.32	0.71	1.30	0.97	201.30	

THE CONTRIBUTING RADIONUCLIDES ARE

NUCLIDE	CRITICAL ORGAN	DOSE	CURIES RELEASED	DECAY CONSTANT (1/SEC)	DECON FACTOR
XE 133	SKIN	31.30	60005.000	0.15E-05	1.00
		TOTAL DOSE	.600E+05		

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